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TECHNICAL REPORT ON AIRPORT CAPACITY AND DELAY STUDIES.(U)

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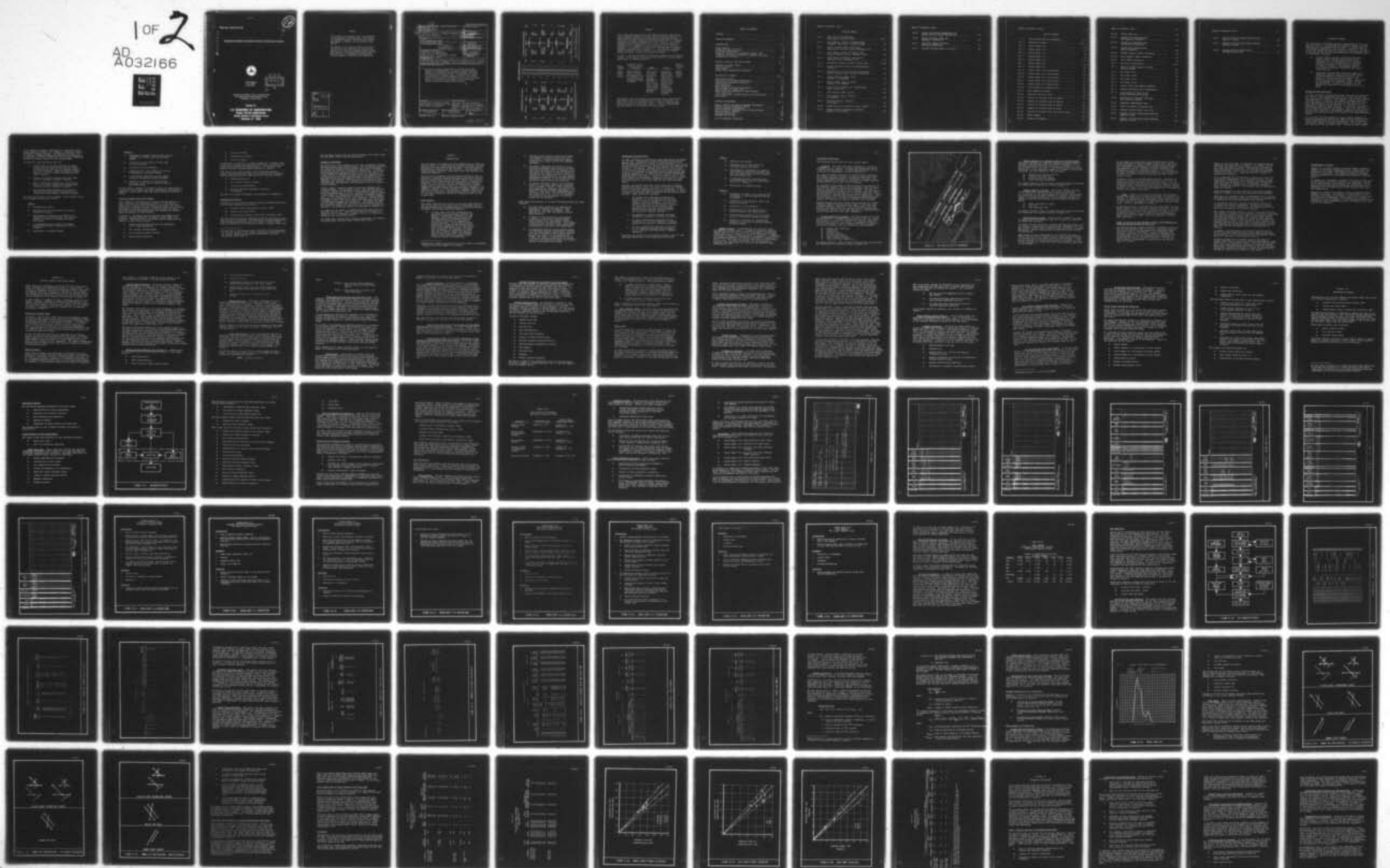

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TECHNICAL REPORT ON AIRPORT CAPACITY AND DELAY STUDIES

Final Report
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Systems Research & Development Service
Washington, D.C. 20590

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16. Abstract

This report contains documentation of the technical studies leading to the preparation of an airfield capacity and delay handbook for the Federal Aviation Administration. The effort was divided into four major areas: (1) introduction, including definitions of airfield capacity and delay; (2) airfield capacity and delay models; (3) validation of capacity and delay models; and (4) Handbook development, including technical studies, presentation concepts, and production.

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METRIC CONVERSION FACTORS

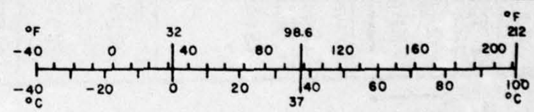
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report was prepared for the Federal Aviation Administration's Systems Research and Development Service as part of its broad research program to develop new and improved methods which will provide a basis for determining how best to increase capacity and minimize congestion on the airfield. The report represents the joint efforts of a project team consisting of Douglas Aircraft Company in association with Peat, Marwick, Mitchell & Co. (PMM&Co.); McDonnell Douglas Automation Company (MCAUTO); and American Airlines, Inc. In addition, Professor Robert Horonjeff of the University of California, Berkeley, served as general advisor to the project team.

As part of the project team's coordinated efforts on the overall project, each organization carried out specific project responsibilities, as summarized below.

Organization	Douglas Aircraft Co. McDonnell Douglas Corporation	PMM&Co.	MCAUTO	American Airlines, Inc.
Overall project responsibility	Prime contractor; overall technical direction and project management; data collection support; computerized section of handbook	Capacity and delay model development; handbook development; management of data collection and analysis; software review, modification, and development; training	Interactive graphics system and real-time simulator feasibility studies; delay model ATC algorithm; model software development; data processing; software documentation; training	General advisory, overall project

The project team appreciates the assistance they received from the Federal Aviation Administration's Airports Service, and other participating branches of FAA, as well as the airlines, various airport sponsors, and other interested organizations who contributed to the efforts of this project.

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EXECUTIVE SUMMARY

For some years, the Federal Aviation Administration (FAA) has been involved in a broad research program to develop reliable planning tools for determining how best to increase capacity and minimize congestion on the airfield. As part of the program, this report describes the results of the four-year effort to develop procedures for the determination of airfield capacity and delay, including:

- A final report entitled "Techniques for Determining Airport Airside Capacity and Delay" (referred to as the Handbook) which contains procedures for the determination of airfield capacity and delay to aircraft for purposes of airport planning. The Handbook covers a wide range of practical conditions and airport configurations.

- Analytical and fast-time simulation models for computing airfield capacity and aircraft delay, including supporting computer software (i.e., batch and on-line computer programs). The models and computer programs, coded in Fortran IV are documented in a companion report. As described herein, successful validation of the models was conducted at three high-activity airports.

Background and Objectives

In 1960, a method for estimating runway capacity was developed for the FAA. This methodology has been in use for more than ten years without review, and during this time, certain changes have affected its validity. For example, widebody aircraft have been placed in service and new aircraft separation rules have evolved because of the magnitude of the wake vortices generated by some of these aircraft. In addition, the current methodology does not permit analysis of the entire airfield, but is mainly confined to the runways. These and other factors, coupled with current and anticipated congestion and delays at high-activity airports, led to the need for the study described herein.

In June 1972, the FAA retained a project team to develop improved procedures and devices for measuring and predicting airfield system capacity and aircraft delay as aids to decision-making with regard to airfield development. The project team was composed of the following firms: Douglas Aircraft Company

of the McDonnell Douglas Corporation in association with Peat, Marwick, Mitchell & Co. (PMM&Co.), McDonnell Douglas Automation Company (MCAUTO), and American Airlines, Inc. In addition, Professor Robert Horonjeff of the Institute of Transportation Studies (University of California, Berkeley) served as a general advisor to the project team.

The specific study objectives were to:

1. Develop new, validated procedures for determining airfield capacity and aircraft delay to serve as the basis for an airfield capacity and delay handbook. These procedures include capacity and delay models and supporting computer software.

2. Prepare an airfield capacity and delay handbook for purposes of airport planning.

3. Make a preliminary examination of the feasibility of a visual display of airfield operations by means of interactive graphics.

4. Train selected FAA personnel in the use of the capacity determination techniques (i.e., capacity and delay models, computer software).

The study was divided into two phases. The principal activities in each phase were as follows:

<u>Phase I</u>

- Handbook user survey.
- Refinement of the definitions of airfield capacity and delay.
- Development of techniques (or models) for estimating capacity and delay, not only for runways, but also for taxiways and apron-gate areas.
- A comprehensive data collection program encompassing aircraft operations at 14 U.S. airports.
- Development of handbook format.

Phase II

- Refinement of Phase I data analysis and refinement of airfield capacity and delay models.

- Validation of the models at three high-activity airports.

- Preparation of the Handbook.

- Preparation of a User Manual for the airfield capacity and delay models.

- A preliminary examination of the feasibility of interactive graphics systems.

- Conduct of a program for training FAA personnel in the use of airfield capacity and delay models.

In this report, emphasis is placed on the first three Phase II activities listed above; the report supplements information in companion reports which cover the other activities in greater detail.

Airfield Capacity and Delay Models

Basic models for estimating capacities and delays were evaluated, selected, and formulated in Phase I of the project. Three types of models were developed to determine the hourly capacity of individual airfield components--models for capacity of runways, a taxiway crossing an active runway, and gates. A fast-time computer simulation model was developed to produce delay information for the Handbook.

In Phase II, refinements and new features were added to the models to increase accuracy, reliability, efficiency, and coverage. Modifications to the runway capacity models during Phase II of the study concerned:

- Runways serving both arrivals and departures (i.e., mixed operations)

- Exit taxiway configurations

- Poor visibility and/or ceiling

- Touch-and-go operations

- Percent arrivals
- Intersecting runways
- Parallel runways

In addition, in Phase II, a capacity model for a taxiway crossing an active runway was developed and refined, reflecting the principal parameters affecting capacity. No revisions were made to the gate capacity models prepared in Phase I.

With regard to the delay model, model refinement began in Phase I and continued into Phase II as the need for additional features became apparent; these additional features include:

- Schedule generator
- Air traffic control features
- Airline gate assignments
- Arrival aircraft lateness in relation to schedule

The details on model refinements are presented in Chapter II.

Validation of Models

Validation of the airfield capacity and delay models was carried out at three high-activity airports.

- Chicago-O'Hare International Airport (ORD)
- Dallas Love Field (DAL)*
- Orange County Airport, Santa Ana, California (SNA)

The validation process was performed to verify the logic of the capacity and delay models. This validation process demonstrated that the models yield aircraft flow rates and travel times within the desired ±15% of observed values. Aircraft flow rates

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*At the time of validation, Dallas Love Field was the principal air carrier airport in the region; since then, the majority of air carrier operations have been transferred to the new Dallas/Fort Worth Airport.

are the basic output from the capacity models, and travel times are the basic output from the delay model.

Handbook Development

The evolution of the Handbook reflects the influence of diverse and often conflicting considerations. One of the most important and recurring considerations involved the trade-off between simplicity and accuracy of Handbook presentation. In addition, an overriding goal of the FAA and the project team was to develop procedures (handbooks, models, etc.) for application to a wide variety of airport planning and design problems, within the spectrum of the resources available to potential users. Therefore, professional judgments on the allocation of project resources were required for a Handbook that correlates with available data and meets the varied needs of the air transportation industry.

A draft report, "Airfield Capacity and Delay Handbook, Preliminary Format," was prepared in April 1974 (during Phase II) to obtain comment on the format of the Handbook from FAA and other representatives of the air transportation industry before a large amount of resources was committed to Handbook production. To the extent possible, the written and verbal comments received are reflected in the final Handbook. Throughout the two-phase effort, technical studies were undertaken in support of Handbook development and production. The status and findings of these studies were reviewed and coordinated with FAA and others at several interim points, and at the conclusion of the work. The technical studies are described in Chapter IV.

In support of the study, a comprehensive data collection program was carried out. Some 150,000 items of data were collected at 18 U.S. airports in Phases I and II, in addition to extensive data from other sources.

All field data, related data reduction summaries, and capacity and delay model runs have been transmitted to FAA.

Chapter I

INTRODUCTION

For some years, the Federal Aviation Administration (FAA) has been involved in a broad research program to develop reliable planning tools for determining how best to increase capacity and minimize congestion on the airfield. (The airfield includes runways, taxiways, apron-gate areas, and approach and departure airspace.)

As part of this program, the FAA retained a project team in June 1972 to develop improved procedures and devices for measuring and predicting airfield system capacity and aircraft delay as aids to decision-making with regard to airfield development. The project team was composed of the following firms: Douglas Aircraft Company of the McDonnell Douglas Corporation in association with Peat, Marwick, Mitchell & Co. (PMM&Co.), McDonnell Douglas Automation Company (MCAUTO), and American Airlines, Inc. In addition, Professor Robert Horonjeff of the Institute of Transportation Studies (University of California, Berkeley) served as a general advisor to the project team.

Study Outputs

This report describes the results of the four-year joint effort by the FAA and the project team in developing the following procedures for the determination of airfield capacity and delay, and related supporting material:

- A final report entitled "Techniques for Determining Airport Airside Capacity and Delay"[1]* (hereinafter referred to as the Handbook) which contains procedures for the determination of airfield capacity and delay to aircraft for purposes of airport planning. The airfield planning process may include several stages from preliminary assessment to detailed evaluation of airfield performance. The Handbook, therefore, is structured to permit the user to choose a method of analysis best suited to his needs. The Handbook covers a wide range of practical conditions and airport configurations.

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*Superscript numbers throughout this report refer to references listed in the final pages of the report.

- Analytical and fast-time simulation models for computing airfield capacity and aircraft delay, including supporting computer software (i.e., batch and on-line computer programs).

- The models, developed for purposes of producing the Handbook, were based on an extensive data collection effort conducted at 14 high-activity airports in the United States. The models and computer programs, coded in Fortran IV, are documented in a user manual[2] (hereinafter referred to as the User Manual). Successful validation of the models was conducted at three high-activity airports.

- An interim technical report[3] that documents Phase I of the study (hereinafter referred to as the Phase I Report). The interim report presents the principal rationale of the models and initial Handbook development activities. The report also documents Phase I data collection (i.e., at 14 U.S. airports) in support of the development of both the models and the Handbook.

Other technical material of interest developed during the study includes:

- All field data collected and compiled for purposes of Handbook development, model development, and model validation. The data are on file with the Federal Aviation Administration.

- A report[4] on the feasibility and benefits of using an interactive graphics system (IGS) display as an input/output device in connection with the delay model. This report is of potential interest to any organization contemplating heavy use of the delay model.

- A preliminary format[5] of the Airfield Capacity and Delay Handbook (hereinafter referred to as the Preliminary Format) which contains the initial concept of the Handbook size, format, and scope. As described herein, as a result of industry coordination in connection with the preliminary format, the initial concept was reviewed and refined.

Background and Objectives

In 1960, a method for estimating runway capacity was developed for the FAA. Subsequently, several documents detailing the method were prepared for airport planning purposes.[6,7,8,9] This methodology has been in use for more than ten years without review, and during this time, certain changes have affected its validity. For example, widebody aircraft have been placed in service and new aircraft separation rules have evolved because of the magnitude of the wake vortices generated by some of these aircraft.[10] In addition, this current methodology does not permit analysis of the entire airfield, but is confined mainly to the runways. These and other factors, coupled with current and anticipated congestion and delays at high-activity airports, led to the need for the study described herein.

Briefly, the overall objective of the study was to produce planning and design tools that would facilitate the determination of airfield capacity and delays to aircraft. In addition, to guide the development of the new methodology, a series of specific objectives were established for the project team's efforts. These objectives included:

1. To develop new, validated procedures for determining airfield capacity and aircraft delay to serve as the basis for an airfield capacity and delay handbook. The new procedures should permit consideration of present and future air traffic control (ATC) equipment and practices; such procedures should include capacity and delay models and supporting computer software.

2. To prepare an airfield capacity and delay handbook for purposes of airport planning.

3. To make a preliminary examination of the feasibility of a visual display of airfield operations by means of interactive graphics.

4. To train selected FAA personnel in the use of the capacity determination techniques (i.e., capacity and delay models, computer software).

The study was divided into two phases--Phases I and II. The principal activities in each phase were as follows:

Phase I

- Handbook user survey.
- Refinement of the definitions of airfield capacity and delay.
- Development of techniques (or models) for estimating capacity and delay, not only for runways but also for taxiways and apron-gate areas.
- A comprehensive data collection program encompassing aircraft operations at 14 U.S. airports.
- Development of handbook format.

Phase II

- Refinement of Phase I data analysis and refinement of airfield capacity and delay models.
- Validation of the models at three high-activity airports.
- Preparation of the Handbook.
- Preparation of a User Manual for the airfield capacity and delay models.
- A preliminary examination of the feasibility of interactive graphics systems.
- Conduct of a program for training FAA personnel in the use of airfield capacity and delay models.

Scope of Report. In documenting the four-year study, the emphasis in this report is placed on presenting technical support and rationale of the first three Phase II activities listed above (i.e., analysis of data and refinement of models, validation of models, and preparation of Handbook). In addition, this report supplements information presented in companion reports[1,2,3,4] concerning the various activities in both phases of the study. As noted previously, all data collected, compiled, and used during the course of the study has been transmitted to FAA.

Principal Definitions

The following definitions are used in this report.

Airfield. The term airfield is defined as a system of components (i.e., runways, taxiways, and apron-gate areas) on which aircraft operate. A simplified diagram of the airfield and its components is shown in Figure I-1.

Air traffic control procedures (including those reflecting the effects of wake vortices) are major factors that influence runway component capacity and delays; therefore, the runway component is defined to encompass the common approach and departure paths to and from the runways.

As described in the Phase I interim report,[3] the capacity of the taxiway component usually is much greater than the capacities of the runway or apron-gate components, with one exception--taxiways crossing an active runway. For this reason, for determining the capacity of the taxiway component, this report covers a taxiway crossing an active runway only. Capacity models for other taxiway situations are presented in the interim report, as is a check to determine whether taxiway capacity is limiting the overall capacity of an airfield.

Because general aviation aircraft do not operate on a fixed schedule, general aviation parking times in the apron area fluctuate widely. Therefore, this report covers only the capacity and delay on an air carrier aircraft parking apron. As a result, the apron-gate area component is sometimes hereinafter referred to as the "gate component."

Hourly Capacity of Runways. The hourly capacity of the runway component is defined as the maximum number of aircraft operations (i.e., arrivals, departures) that can take place on the runway component in an hour. The maximum number of aircraft operations on this component depends on a number of conditions including, but not limited to, the following:

- Ceiling and visibility
- Runway use
- Aircraft mix
- Percent arrivals
- Percent touch-and-go
- Exit taxiway location
- Other operating conditions

To compute capacity, each of these conditions must be specified; the conditions are detailed in other volumes.[1,2,3]

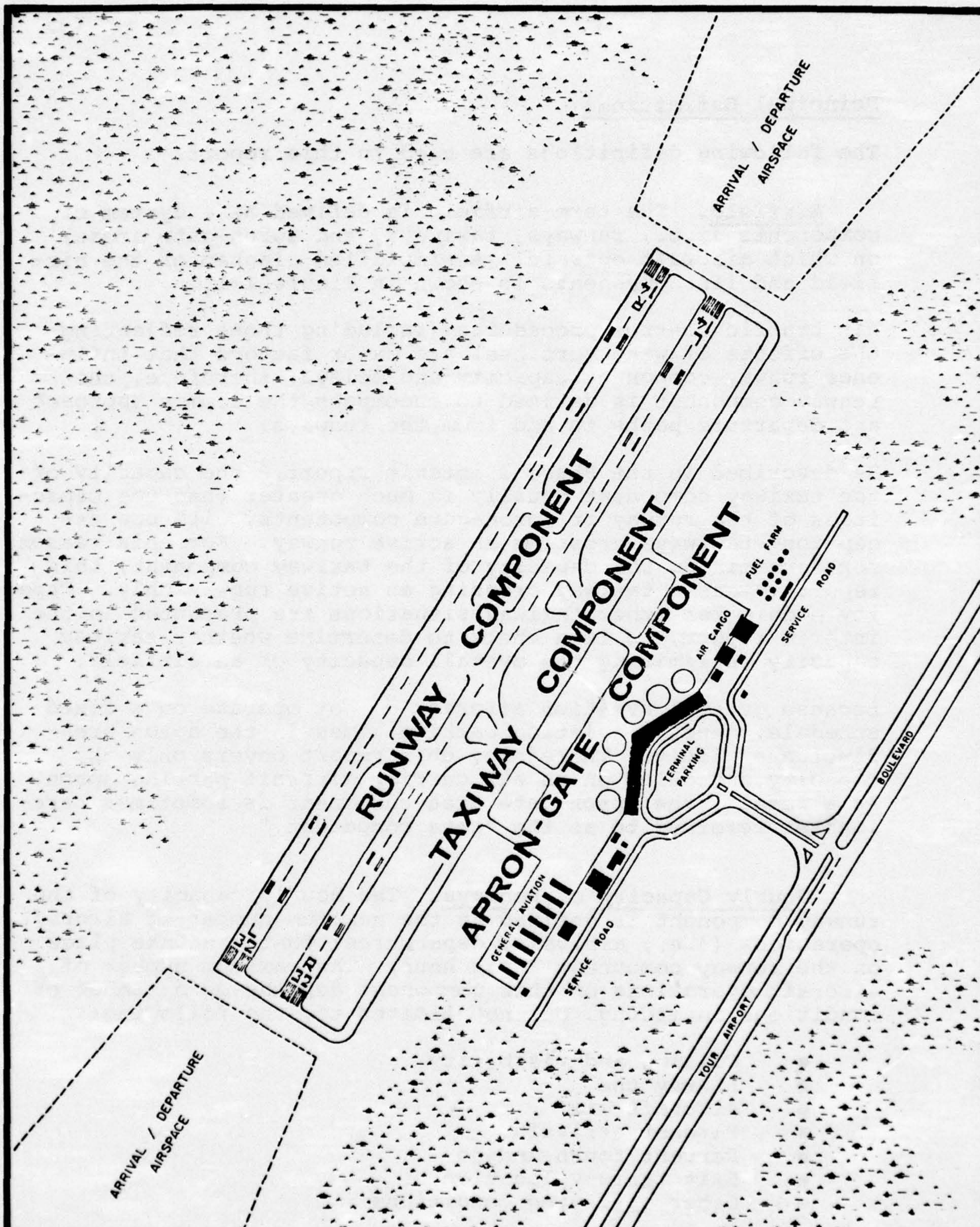

FIGURE I-1. THE AIRFIELD AND ITS COMPONENTS

Hourly Capacity of a Taxiway Crossing an Active Runway. The hourly capacity of a taxiway crossing an active runway is defined as the maximum number of aircraft operations (i.e., crossing movements) that can take place in an hour on a taxiway crossing an active runway. The maximum number of aircraft operations on this component depends on a number of conditions including, but not limited to, the following:

- Intersecting taxiway location
- Runway operations rate
- Aircraft mix using runway
- Other operating conditions

To compute capacity, each of these conditions must be specified; the conditions are detailed in other volumes.[1,2,3]

Hourly Capacity of Gates. The hourly capacity of gates is defined as the maximum number of aircraft operations (i.e., arrivals to the gates, departures from the gates) that can take place on the gate component in an hour. The maximum number of aircraft operations on this component depends on a number of conditions including, but not limited to, the following:

- Number and types of gates
- Gate mix
- Gate occupancy time

To compute capacity, each of these conditions must be specified; the conditions are detailed in other volumes.[1,2,3]

Annual Service Volume. Annual service volume is a level of annual aircraft operations that may be used as a reference in preliminary planning.

As annual aircraft operations increase and approach annual service volume, average delay to each aircraft throughout the year may increase rapidly with relatively small increases in aircraft operations, thereby causing levels of service on the airfield to deteriorate.

When annual aircraft operations on the airfield are equal to annual service volume, average delay to each aircraft throughout the year are on the order of one to four minutes. A more precise estimate of actual average delay to aircraft at a particular airport can be obtained using the procedures described in the Handbook.

If the number of annual operations exceeds annual service volume, moderate or severe congestion may occur, similar to that experienced at several of the airports surveyed during the development of the Handbook (including Chicago O'Hare International Airport, LaGuardia Airport, and William B. Hartsfield Atlanta International Airport). For analyses of airfield improvements, aircraft delays also can be important at levels of annual aircraft operations less than annual service volume.

Therefore, delays to aircraft should also be considered in planning and evaluating airfield improvements at levels of annual operations less than annual service volume. In some instances, when annual demand is expected to approach one-half of annual service volume within the planning horizon, nominal construction costs of airfield improvements may be balanced by savings in aircraft delay costs.

Delay. Delay to aircraft is defined as the difference between the actual time it takes an aircraft to operate on an airfield (or component) and the normal time it would take the aircraft to operate without interference from other aircraft on the airfield (or component) under specific operating conditions. Delay is expressed in minutes.

As described herein, procedures have been developed for estimating hourly, daily, and annual delay to aircraft. In addition, delays on the airfield, reflecting the lack of capacity in the airspace or due to the saturation or closure of a destination airport, can be evaluated using the simulation model, provided that model inputs are adjusted to reflect such conditions.

Notes on the Use of the Handbook, Models, and Computer Programs to Determine Capacity and Delay

As stated previously, hourly capacity is defined in this report as the maximum number of aircraft operations that the airfield or one of its components can accommodate under specified operating conditions. Capacity expresses the physical capability of an airfield and its components and is independent of both the magnitude and fluctuation of demand and the level of delay to aircraft. In this context, demand is independent of capacity and the level of delay to aircraft.

Delay, on the other hand, is dependent on capacity and the magnitude and fluctuation in demand. For example, delays can occur even when the demand averaged over one hour is less than the hourly capacity. Such delays occur because demand fluctuates within an hour so that during some small intervals of time (i.e., less than one hour), demand is greater than capacity.

If the magnitude and fluctuations in demand are fixed, the only way to reduce delay is to increase capacity. On the other hand, if demand can be manipulated to produce a more uniform pattern of demand (i.e., reduce peaks in demand), then delay can be reduced without increasing capacity. Thus, estimating capacity is an integral step in determining delay to aircraft.

Numerical examples of this important relationship between capacity, demand, and delay are presented in the Handbook.

Capacity is an important index of performance of an airfield but should not be used as the sole criterion for determining if additional airfield improvements are required.

In preliminary planning, several alternative airfield improvements are usually considered. Capacity is a useful criterion for initial screening of the alternatives and for selecting alternatives for further analysis.

When demand approaches capacity, delays to aircraft build up very rapidly. Because of the congestion that may be associated with rapid buildups of delay, users of this report should exercise caution when planning for airports where demands are expected to approach capacity levels for more than very short periods of time. Also, because of their economic importance, estimating the magnitude of delays usually is much more important in determining the justification and requirement for airfield improvements than a determination of capacity.

In summary, the operational and economic implications of delay to aircraft generally dictate that delay to aircraft be included in airfield planning studies considerably before demand is expected to reach capacity levels.

Although information on airfield capacity and delay is clearly important for justifying airfield improvements, other factors (e.g., environmental impact, financial implications) may in the final analysis be of equal, or possibly greater importance. Although these other factors must be considered before final decisions are made on airport planning and improvements, they are not treated in this report.

Organization of Report

Chapter II, Airfield Capacity and Delay Models, presents a summary of the Phase I modeling efforts, followed by a description of the model refinements and features added in Phase II of the study. This chapter supports the comprehensive presentation of the models and software in the user manual.[2]

In Chapter III, Validation of Models, the nature of the validation process, the data collection for validation, as well as the data reduction and analysis, are discussed. The sequential steps taken during validation are described, as is preparation of the model inputs, model outputs, and field data comparisons.

Chapter IV, Handbook Development, briefly summarizes Phase I Handbook activities. In addition, the rationale for the graphical presentations developed in Phase II for both capacity and delay is presented. This chapter also contains a discussion of the development of the preliminary format of the Handbook as well as subsequent factors influencing the final form of the Handbook.[1]

Chapter II

AIRFIELD CAPACITY AND DELAY MODELS

Basic models for estimating capacities and delays were evaluated, selected, and formulated in Phase I of the project. In Phase II, refinements and new features were added to the models to increase accuracy, reliability, efficiency, and coverage. The models, which are documented in detail in the User Manual, were validated as described in Chapter III and then were used in the production of the Handbook as described in Chapter IV.

In this chapter, a summary of Phase I modeling efforts is presented. However, inasmuch as extensive documentation of the models and supporting software is set forth in the User Manual and the Phase I Report, the principal emphasis in this chapter is placed on presenting technical support for the modeling activities in Phase II.

Selection of Model Types

In Phase I, several basic model types were considered, including the two most common types--analytical and simulation models. In choosing the models for determining capacity and delay, the following factors were of principal importance: (1) accuracy of the model outputs and the context in which they will be used; (2) cost of providing data for Handbook development; (3) time available for developing the required information; and (4) compatibility with other project applications (such as the interactive graphics display).

In view of these and other factors described in the Phase I Report, the project team selected analytical models for determining capacity of the airfield and its components and a fast-time computer simulation model for determining delay to aircraft on the airfield and its components. The models subsequently developed deal parametrically with the most significant airfield system characteristics.

Capacity Models

Three types of models were developed to determine the hourly capacity of individual airfield components--models for capacity of runways, a taxiway crossing an active runway, and gates. In all the capacity models, capacity is calculated as the inverse of a weighted average service time of all aircraft being served. For example, if the weighted average service time for operations

on a runway is 45 seconds, capacity of the runway is one operation per 45 seconds, or 80 operations per hour.

Runway Capacity Models. The runway capacity models developed in Phase I are based on the concept that aircraft can be represented as attempting to arrive at points in space at particular times (i.e., maintaining intended lateral, longitudinal, and vertical positions in space at particular times, referred to as "station keeping"). It was assumed that deviations from a station can be considered as being normally distributed with zero mean, and that deviations of one aircraft around its station are independent of the deviations of all other aircraft. Because of these deviations, controllers tend to increase the separations between operations by an amount of time that is called a buffer in the model.

The capacity model uses a set of input parameters to determine the minimum time separation (or interval) between operations. First, the time separations are estimated by assuming that there are no deviations from the intended station of each aircraft. Then a buffer time is added that allows for random deviations; thus, the minimum time interval between operations is derived. The use of these time intervals can best be explained by reference to the space-time diagrams contained in the User Manual. Conceptually, similar runway capacity models have been used in the past.[11,12]

The major differences between the runway capacity models developed in this study and previously documented models include: (1) wake turbulence separations are accounted for; (2) many different runway use configurations are modeled; (3) continuous and realistic variation of the percentage of arrivals is possible; (4) touch-and-go operations can be accounted for; (5) the type and location of exit taxiways can be varied; and (6) ATC operating practices and procedures under different weather conditions are more accurately replicated. These differences allow a more complete and realistic treatment of runway capacity than previously possible.

Runway Capacity Modeling During Phase II. Modifications to the runway capacity models during Phase II of the study concern:

- Mixed operations.
- Exit configurations.
- Poor visibility and/or ceiling (PVC).

- Touch-and-go operations.
- Percent arrivals.
- Intersecting runway use with arrivals on one runway and departures on the other runway.
- Intersecting runway use with mixed operations on one runway and departures on the other runway.
- Parallel runway use to reflect ATC rule change.

Mixed Operations. The models developed in Phase I treated interarrival times as if they were fixed values (i.e., mean value plus a buffer). However, it is more realistic to characterize interarrival times as random variables. Because of the deterministic nature of the initial formulation, the models in Phase I tended to overestimate or underestimate capacity, particularly in terms of the number of departures. In Phase II, the fixed values in the models were replaced by random variables, thereby increasing realism and accuracy in connection with air traffic controller actions and aircraft operations and performance. The mixed operations model refinements allow up to three departures to take place between arrivals, provided a sufficient gap between arrivals is available.

Further details on the mixed operations features of the runway capacity models are set forth on pages I.22 through I.27 of the User Manual.

Exit Configuration. Exit configuration was not incorporated into the runway capacity models during Phase I; at that time, the model user was required to estimate the effect of each particular exit configuration on arrival runway occupancy times. During Phase II, a further analysis of data collected in Phase I indicated that the effect of exit configuration capacity should be included in the models. This effect was incorporated in the runway capacity models as follows.

A weighted runway occupancy time is used for each aircraft class. The weighted runway occupancy time $\overline{AR(h)}$ for class h aircraft is calculated as follows:

$$\overline{AR(h)} = \sum_{x}\{y(h,x)\ AR(h,x)\}$$

where

AR(h,X) = the arrival runway occupancy time of class h aircraft using exit x

y(h,x) = the proportion of class h aircraft using exit x

Poor Visibility and Ceiling Conditions (PVC). For purposes of determining the hourly capacity of runways in the Handbook, the terms VFR and IFR are used as measures relating to ceiling and visibility. Although appropriate for the vast majority of Handbook applications, the use of VFR and IFR is a simplification of real-world operating procedures and practices. In reality, the effect of ceiling and visibility on capacity is complex and varies from airport to airport depending on actual site conditions, etc.

In the planning of high-activity airports, the occurrence of certain visibility and ceiling conditions (i.e., poor visibility and ceiling or "PVC") may be significant enough to warrant further analysis of runway capacity during IFR conditions.

As a result, for purposes of Handbook production, a variation of the runway capacity models was formulated in Phase II to cover PVC conditions. In the model, PVC is defined as visibility and ceiling conditions which are just above airport operating minima (e.g., ceiling less than 500 feet and/or visibility less than one statute mile) and, therefore, no relief from the 2-mile rule is allowed (i.e., a departure has to be held if it would come within 2 nautical miles of an arrival on a dependent runway). Thus, capacity values in PVC represent the maximum number of operations that are expected to take place at the low end of the ceiling and visibility spectrum.

These aspects of the runway capacity models are set forth on pages I.22 through I.24 of the User Manual.

Touch-and-Go. During Phase II, model logic was incorporated into the single runway and two close parallel runway capacity models to allow the computation of hourly runway capacity when touch-and-go operations occur. The logic for computation of capacity with touch-and-go operations for other runway use configurations in the Handbook is the same as, or a combination of, the logic in these two models. The logic allows the user to specify the proportion of touch-and-go operations that take place on the runways.

Further details of the touch-and-go logic are presented in pages I.31 through I.36 of the User Manual.

Percent Arrivals. Early in Phase II, a technique for determining airfield runway capacity for a desired level of percent arrivals was developed by "stretching" the inter-arrival gaps between aircraft. However, subsequent investigations revealed that this technique was not sufficient because: (1) an iterative process was required to ascertain the appropriate interarrival spacing; (2) for mixed operations, a percent arrival less than 25% could not be achieved since the models assume a maximum of three departures between arrivals; and (3) the model process of stretching all interarrival gaps by the same amount resulted in an unrealistic loss in capacity and lower capacity values than would be expected.

Therefore, further modeling activities were undertaken and a procedure for the more efficient use of computer time was developed to accommodate differing percent arrivals. The new percent arrivals technique incorporates a procedure that selects a more appropriate runway use(s) by inactivating an arrival stream(s) to achieve the appropriate percent arrivals.

The improved technique for dealing with percent arrivals is detailed in pages I.27 through I.30 of the User Manual.

Intersecting Runway Use with Arrivals on One Runway and Departures on the Other Runway. The model was revised to accept two 4 x 4 separation matrices as inputs. These two matrices define the arrival-departure separations (in seconds) and the departure-arrival separation (in nautical miles) that apply on the intersecting runways.

Intersecting Runway Use of Mixed Operations on One Runway and Departures on the Other Runway. The Phase I model for intersecting runways with mixed operations on one runway and departures on the other was no longer appropriate because of the logic changes in the preceding paragraphs. Therefore, a new model was prepared to overcome the increasingly complex problems associated with modification of the initial model. The new model performs a comparison of the capacity from the single runway model and that of the intersecting runway model described in the previous paragraphs. The maximum of these two capacities is then taken as the capacity of this runway use.

Parallel Runway Use to Reflect ATC Rule Change. Program logic was revised to correctly compute IFR separations for arrivals on adjacent parallel runways that are 2,500 to 4,299 feet apart by eliminating wake turbulence effects. For example, on the same runway, new ATC rules require Class A aircraft to follow Class C aircraft by at least 4 nautical miles. On adjacent runways separated by 2,500 to 4,299 feet this requirement is reduced to 3 nautical miles. A similar revision was made to VFR separations for arrivals on adjacent parallel runways that are 700 to 2,499 feet apart.

Taxiway Capacity Model. As described in Chapter I, the capacity of the taxiway component usually is much greater than the capacities of the runway or gate components, with one exception--taxiways crossing an active runway. For this reason, in Phase I it was decided that, for determining the capacity of the taxiway component, models would be developed only for a taxiway crossing an active runway.

Inputs to the model include:

- Runway flow rates
- Percent arrivals
- Aircraft mix
- Exit configuration
- ATC rules and procedures
- Length of common approach path
- Aircraft operating characteristics
- Taxiway/runway intersection location
- Taxi speeds
- Aircraft size
- Headways
- Runway clearance distance

The model is based on the assumptions that (1) aircraft cross the active runway at a single location, and (2) all time separations are average values.

The taxiway crossing model, which was developed early in Phase II and documented in the User Manual, was refined as a result of further analysis. These refinements include:

- A buffer time which is added after a runway operation crosses the taxiway/runway intersection (or after the operation has cleared the runway) before the taxiing aircraft can start its crossing movement. This buffer time is called BUFFA or BUFFD depending on whether the runway operation is an arrival or a departure.
- A runway/taxiway intersection clearance time, (TASR) which is now a model input.

Further details of the taxiway capacity model are set forth in pages I.36 through I.44 of the User Manual.

Gate Capacity Model. Two basic gate capacity models were developed in Phase I; the first is a simplified model which assumes that aircraft can use all available gates, and the second is a more general model which assumes that some aircraft cannot use all the available gates. The models are described in detail in the Phase I Report and the User Manual. No refinements were made to the gate capacity models in Phase II.

Delay Model

As noted previously, the project team decided in Phase I to develop a fast-time computer simulation model to produce delay information for the Handbook. Delay to aircraft is defined herein as the difference between the actual time it takes an aircraft to operate on an airfield (or component) and the normal time it would take the aircraft to operate without interference from other aircraft on the airfield (or component) under a specific operating condition. Therefore, computed delays are equal to increases in travel time attributable to congestion on the airfield and in the adjacent airspace.

In order to provide information on delay and travel time to the level and detail desired, an airfield simulation model was developed. This model, which is an extension of previous work[13,14] is a critical events model that employs Monte Carlo sampling techniques. Because of the modular structure of the

model, analysis of the total airfield or its individual components can be performed by manipulation of the model inputs. This approach is more flexible and efficient than having separate submodels for the individual components and a composite model for the total airfield.

Model refinement began in Phase I and continued into Phase II as the need for additional features became apparent. Comprehensive model documentation is included in the User Manual. A summary description of the model is presented below.

Summary Description of Model. The model operates by tracing the path of each aircraft through space and time on the airfield. The airfield is represented by a series of links and nodes depicting all possible paths an aircraft could follow. The traces of the paths of all aircraft on the airfield are made by continually advancing clock time and recording the new location of the aircraft. The records of aircraft movement are then processed by the model to produce desired outputs including delays and flow rates.

Variable time increments are used as the time flow mechanism (i.e., clock time is advanced by the amount necessary to cause the next most imminent event to take place). Therefore, running time for the model is dependent on the levels of aircraft demand and the size of the airfield for any particular application.

Demand Process. Information on arriving and departing aircraft is produced by a demand-generating mechanism. The demand-generating mechanism accepts two forms of inputs. These inputs may be (1) an actual schedule of aircraft movements which specifies aircraft class, scheduled arrival and departure times, and arrival and departure runways; or (2) the desired aircraft mix, flow rates, and runway utilizations.

Movement of Aircraft. For each arrival aircraft, an approach speed is assigned from an empirical distribution according to the class of the aircraft. For each arrival pair, interarrival times, approach speeds, and wake turbulence characteristics are checked so that sufficient separation exists on the common approach path.

As each aircraft arrives over the threshold, an exit taxiway and associated runway occupancy time are assigned to the aircraft. These assignments are based on empirical distributions

which take into account such factors as exit location and type, aircraft class, condition of the runway, and weather. The aircraft's routing to the gate or basing area is established in the following manner. As an air carrier aircraft exits the runway, a check is made on the availability of a gate of the correct size which belongs to the airline under consideration. If an appropriate gate will be available by the time the aircraft reaches the apron-gate area, the aircraft's route to the gate is assigned on the basis of the exit taxiway used and the gate location. In the event a gate is not available, the aircraft is routed to a holding area where further checks on gate availability are made. In the case of general aviation or military aircraft, the aircraft's route to the basing area is assigned on the basis of the exit taxiway used and the location of the basing area.

Once an aircraft's route to the gate or basing area has been established, the aircraft is moved along its route from link-to-link on the airfield network. Checks are made at each link to determine whether the next link on the route is available or occupied by another aircraft. If the next link is occupied, the aircraft is not moved until the link is vacated. Thus, the travel time is increased for the particular aircraft, and delay is incurred. When the aircraft reaches its gate, a gate occupancy time is assigned from empirical distributions and is added to the gate arrival time. This information determines the earliest time when the aircraft could leave the gate. The empirical distributions for gate occupancy time may reflect the typical bunching of the schedules of air carrier departures. When an aircraft is ready to leave the gate, a check is made to ensure that the ramp area is clear for push-back. The route to the departure runway is determined by the aircraft's basing area or gate location, the aircraft class, and the departure runways in use at that particular time.

In the case of general aviation or military aircraft, when the aircraft reaches the basing area, it is assumed to have left the system. This assumption is necessary because of the unstructured nature of general aviation or military operations on the apron. Consequently, the flow of aircraft from the basing area is generated via the demand-generating mechanism, using desired mix and flow rates as inputs. This procedure will produce an expected departure time from the basing area for each general aviation aircraft. The route to the departure runway will then be established by the location of the basing area and the departure runways in use.

When an aircraft reaches the threshold of the departure runway, compliance with ATC practices is checked and confirmed before the aircraft is cleared for takeoff. The following checks are made:

- Has the previous dependent arrival cleared the runway?
- Is there sufficient separation from the next incoming dependent arrival?
- Is there sufficient separation from the previous dependent departure?

If all these checks are positive, the aircraft is cleared for takeoff.

<u>Delay Modeling During Phase II</u>. The following model features were developed during Phase II. All of the Phase II modeling in connection with the delay model is fully documented in the computer programs contained in the User Manual.

<u>Schedule Generator</u>. Initially the delay model required the model user to develop a detailed schedule of aircraft demand for use of the airfield. The schedule generator, therefore, was formulated to provide the model user with an option in the event a detailed schedule is not available. The schedule generator is equally applicable for use in model applications involving air carrier activity and general aviation activity where only gross approximations of aircraft demand characteristics are available. In order to use the schedule generator, the following additional information must be input to the model:

- Desired hourly flow rate
- Aircraft mix
- Proportions of air carrier and general aviation aircraft
- Runway utilization by arrivals and departures of each aircraft class
- Percent touch-and-go operations
- Utilization of general aviation basing areas

Based on the above inputs, the model generates a "schedule." Interarrival times are produced for each aircraft in the system (i.e., at the beginning of the common approach path or at the arrival runway threshold). For air carrier aircraft, this information, together with data for gate service time, is used to generate "scheduled" departure times. Gate assignments are made based on the airline and aircraft type under consideration. The method of treating general aviation and military aircraft was described previously in the description of movement of aircraft.

Air Traffic Control (ATC) Features. Several air traffic control logic features were implemented in Phase II. These features were intended to make the model more generally applicable and easier to use.

An ATC algorithm was developed which allows the user to specify appropriate separations between aircraft on the same runway and on dependent runways for a particular airport. These separations are defined for an arrival following an arrival, a departure following an arrival, a departure following a departure, and an arrival following a departure. For each aircraft operation, the model checks that sufficient separation exists between aircraft on the same runway or any dependent runway.

Another ATC feature was developed to reflect a controller practice observed in the field. This particular feature causes an increase of arrival aircraft spacings on final approach to allow lengthy departure queues to be reduced. The minimum length of the departure queue which causes the interarrival spacing to be increased must be specified by the user just as the desired interarrival spacing (in minutes) must be specified.

Airline Specific Gate Assignments. An option incorporated in the model permits the user the option of specifying which gates can be used by which aircraft of which airline.* During the operation of the model, a check is made for the aircraft under consideration to determine if the preferred gate for that aircraft is available. If the gate is available, the aircraft is assigned to that particular gate. In the event there are no gates belonging to the airline in question that can accommodate the aircraft, the aircraft is dispatched to a holding area until a gate is available.

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*Developed as part of a prior assignment.

Arrival Aircraft Lateness. This feature is only activated if the user inputs an airline schedule. Each aircraft has assigned to it a "lateness" time that is added to the aircraft's scheduled time of arrival. The lateness, which may be positive or negative, is generated by the model using a lateness distribution and the random number generator. This particular model feature is desirable because of the perturbations of the scheduled aircraft arrival times that actually occur in the field.

Annual Delay Aggregation Technique

Annual delay is made up of the sum of the individual aircraft delays that occur in each hour of the 365 days of the year. Consequently, a technique was developed that calculates annual delay by aggregating these hourly and daily delays on an annual basis.

The manual aggregation technique is described in Chapter 2 of the Handbook. Because of the time-consuming nature of these computations the technique was computerized in two versions. The on-line version described is in Chapter 3 of the Handbook. The batch version is briefly described in Chapter 4 of the Handbook and is further described below.

The technique involves computing hourly and daily delays for a number of week groups and day groups that are representative of the seasonal and daily variations in demand and weather conditions. The computational process parallels that described in Paragraphs 27 and 28 of the Handbook. Inputs to the technique are as follows:

- Annual demand
- Weekly demand as a percentage of annual demand
- Daily demand as a percentage of weekly demand
- Hourly demand as a percentage of daily demand
- Demand profile factor
- Runway use demand factor
- Weather group demand factor

- Weather occurrence
- Runway use occurrence
- Capacities for each runway use and weather combination

The following steps are performed in the computational process:

1. Compute daily demand for each week-group/ day-group/weather-group combination.
2. Compute hourly demands for each of the daily demands computed in step 1.
3. Compute demand/capacity ratios and delay factors for each hourly demand computed in step 2, in accordance with the procedures set forth in Paragraphs 27 and 28 of the Handbook.
4. Determine average aircraft delays from the equivalent of Figures 2-68 and 2-69 of the Handbook.
5. Determine total delay for each week-group/ day-group/weather-group/runway use combination.
6. Aggregate the total daily delays from step 5 based on the relative occurrence of the week-groups, day-groups, weather-groups, and runway uses to determine the annual delay to aircraft.

The outputs from the batch model are:

- Average annual delay per aircraft
- Total annual delay to aircraft
- Distribution of average aircraft delays

Chapter III

VALIDATION OF MODELS

Validation of the airfield capacity and delay models was carried out at three high-activity airports.

- Chicago-O'Hare International Airport (ORD)
- Dallas Love Field (DAL)*
- Orange County Airport, Santa Ana, California (SNA)

The validation process was performed to verify the logic of the capacity and delay models. This validation process demonstrated that the models yielded aircraft flow rates and travel times within the desired ±15% of observed values. Aircraft flow rates are the basic output from the capacity models, and travel times are the basic output from the delay model.

Three types of models were validated:

- Runway capacity models
- Gate capacity models
- Airfield delay models

Validation efforts involving a fourth type of model, a capacity model of a taxiway crossing an active runway, were curtailed because sufficient field data were not available.

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*At the time of validation, it should be noted that Dallas Love Field was the principal air carrier airport in the region; since then, the majority of air carrier operations have been transferred to the new Dallas/Fort Worth Airport.

Validation Process

The validation process consisted of five major steps:

- Identification of data requirements
- Selection of validation airports
- Data collection and reduction
- Running of models
- Comparison of model outputs with field data

The various steps in the validation process are shown in Figure III-1.

Identification of Data Requirements

Two types of data were required for the validation process:

- Model input data
- Data for validation comparison

Model Input Data. Model input data concern the operating conditions in effect at the airports at the time the data for validation comparison were collected. The model input data for the runway capacity models include the following:

- Runway uses/operating strategy
- Aircraft mix on each runway
- Exit times and utilization
- Arrival and departure air separations
- Departure runway occupancy times
- Length of common approach path(s)
- Weather conditions
- Percent arrivals

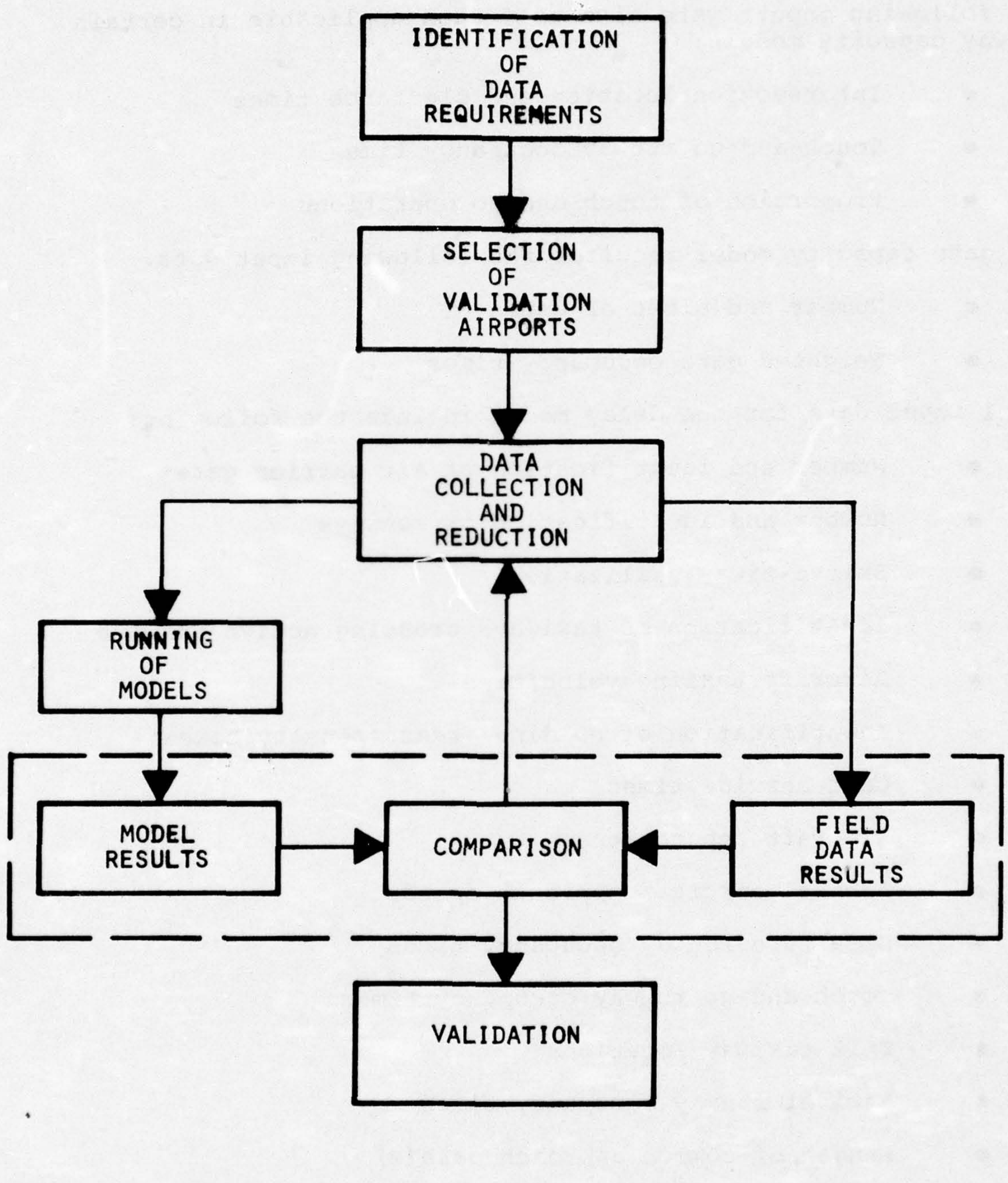

FIGURE III-1. VALIDATION PROCESS

The following inputs were also used when applicable in certain runway capacity models:

- Intersection location and clearance times
- Touch-and-go runway occupancy times
- Proportion of touch-and-go operations

The gate capacity model requires the following input data:

- Number and sizes of gates
- Weighted gate occupancy times

Model input data for the delay model include the following:

- Number and identification of air carrier gates
- Number and identification of runways
- Exit taxiway utilization
- Identification of taxiways crossing active runways
- Aircraft taxiing velocities
- Identification of holding areas (penalty boxes)
- Gate service times
- Aircraft separations
- Arrival aircraft approach speeds
- Departure runway occupancy times
- Touch-and-go runway occupancy times
- Exit taxiway locations
- Arrival runway occupancy times
- Length of common approach path(s)
- Identification of general aviation basing areas
- Identification of two-way taxiways

- Link data
- Route data
- Schedule data

Data for Validation Comparison. Data for validation comparison correspond to the outputs from the capacity and delay models. These data collected in the field for the runway and gate capacity models consisted of flow rates under close-to-capacity conditions. The data for validation comparison collected in the field for the delay model were travel times, i.e., the basic model output. A subsequent step in the overall validation process was to compare the flow rates and travel times produced by the models with the observed validation data.

All data items for validation were collected in Phase II except for those data concerning aircraft operating characteristics and aircraft separations which were available as a result of Phase I data collection efforts.

Selection of Validation Airports

The following procedure was used in the selection of validation airports from the various candidate airports under consideration. The selection was primarily guided by the desire to validate the models at a level of operations close to saturation (i.e., demand about equal to, or exceeding capacity) and over a representative range of conditions, including:

- Runway use (single, intersecting, parallel runways)
- Weather (IFR, VFR)
- Aircraft mix (high percent of air carrier, relatively even balance of air carrier and general aviation, high percent of general aviation)
- Percent touch-and-go (from 0% upward)

Inasmuch as all runway capacity models developed in the study involve the runway uses or combinations of the three uses listed above, it was particularly important to undertake validation on these three particular runway uses.

Other factors were considered in the evaluation of candidate airports selected for validation such as the availability of

applicable models, types of navaids, the degree of restrictions on airspace usage, runway length, exit taxiway configurations, airport elevation, and previous experience at the airport. Another important factor was the number and availability of surveillance equipment at the airports to assist in data collection, particularly during IFR weather conditions. The most desired equipment included an automated radar terminal system III (ARTS-III) and aircraft surface detection equipment (ASDE).

Based on the factors outlined above, five airports were selected for validation data collection, as follows:

Boston-Logan International Airport (BOS)

Chicago-O'Hare International Airport (ORD)

Dallas Love Field (DAL)

Orange County Airport, Santa Ana, California (SNA)

Santa Monica Airport, Santa Monica, California (SMO)

Due to budget constraints later in the study, it was determined that model validation should be carried out for three of the five airports. The three airports ultimately selected for validation were Chicago O'Hare International Airport, Dallas Love Field, and Orange County Airport. As noted previously, Dallas Love Field was the principal air carrier airport in the region at the time of airport selection and subsequent data collection.

Data Collection

After the data requirements were defined and the five airports were chosen, steps were initiated to organize and coordinate the actual collection of data. This activity initially involved the development of a time schedule and the conduct of presurvey coordination.

Time Schedule. The time schedule developed for data collection is shown in Table III-1. Data collection started on August 30, 1973 at Orange County Airport (SNA) and was completed on November 16, 1973 at Dallas Love Field (DAL). Survey teams spent up to two weeks collecting data at each airport.

Table III-1

DATA COLLECTION SCHEDULE
FAA Airport Capacity Study

Location	Presurvey Date	Survey Data Collection Dates
Orange County Airport	August 24, 1973	August 30-September 4, 1973
Boston-Logan International Airport	September 11, 1973	September 24-October 5, 1973
Santa Monica Airport	September 17, 1973	September 28-October 13, 1973
Chicago O'Hare International Airport	October 10, 1973	October 22-November 2, 1973
Dallas Love Field	November 1, 1973	November 5-16, 1973

<u>Presurvey Visits</u>. FAA and project team representatives visited each of the five airports in advance of the actual data collection efforts. These visits were intended to:

- Inform the airport sponsor and air traffic control personnel of the forthcoming survey and secure their cooperation in the data collection effort.

- Undertake preliminary field work.

Prior to these visits, FAA and project team representatives made numerous contacts by letter and telephone to ensure that the presurvey visits would be attended by appropriate personnel concerned with data collection at the airports. This coordination was vital to the success of the data collection activities.

The preliminary field work carried out during the presurvey visits included:

- Collection of readily available data such as airport layout plans and air traffic statistics.

- Review of the availability of on-site equipment (radar displays, communication headsets, etc.).

- Discussions of problems that might arise during the survey due to local conditions (such as closure of segments of the airfield for maintenance; night observations; effects of vacations, sick leave, and other time-off on personnel availability, etc.).

<u>Other Presurvey Activities</u>. Other activities conducted prior to the field collection of data included:

- Preparation of data forms and refinement of data collection procedures.

- Formulation of data collection teams.

- Conduct of data collection orientation.

- Processing of information obtained during presurvey visits.

- Procurement of necessary equipment and material (e.g., stopwatches, digital clocks, field glasses, checklists, forms, charts, airfield network diagrams, maps, tape recorders, earphones, VHF receivers).

- Initiation of data collection training for survey team members.
- Arrangements for survey team meetings to be held during the data collection period to improve data collection procedures during the remainder of the project.
- Preparation of a final checklist for arrangements and personal contacts for visits.

These activities, coordinated with the FAA, concluded with the preparation of material for survey team members, including instructions, survey schedules, equipment lists, detailed instructions for recording the data, and security identification badges.

Data Forms. Seven forms were prepared for collecting data on the following kinds of aircraft activity (see Figures III-2 through III-8:

- Coding Sheet II-A, Data Collection Cover Sheet
- Coding Sheet II-B, Aircraft Flow Rate--gates
- Coding Sheet II-C, Aircraft Flow Rate--Approach Airspace
- Coding Sheet II-D, Aircraft Flow Rate--Runways, Gates, Approach
- Coding Sheet II-E, Gate Utilization/Occupancy
- Coding Sheet II-F, Runway Crossing
- Coding Sheet II-G, Taxiway Headways

To expedite the reduction of massive amounts of data, data forms were prepared in the format of computer coding sheets. The data forms, therefore, were compatible with direct keypunching; data reduction programming was keyed to the forms.

A brief description of instructions, available equipment for data collection, and the objective for Coding Sheets II-B through II-G are presented in Figures III-9 through III-14. Coding Sheet II-A is self explanatory; therefore, no instructions were prepared.

AIRPØRT : ØRD
DATA SET NUMBER : 999

DATE ØF SURVEY : 10/15/73
RECØRDER : JOHN DOE

BEGIN TIME ØF DATA SET : 1300 GMT
COMPLETION TIME ØF DATA SET : 1500 GMT

WEATHER INFØ : VISIBILITY = 30 @1300 20@ 1400 15 @1420

CEILING = UNL @1300

TEMPERATURE = 76 @1300

WIND DIRECTIØN/SPEED = 30/15 @1300

RUNWAY USE CØNFIGURATIØN : ARRIVALS = RWYS 32L, 32R

DEPARTURES = RWYS 27L, 32R, 32L

LENGTH ØF CØMMØN APPRØACH = 5.6 RWY 32L

6.0 RWY 32R

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FIGURE III-2. CODING SHEET II-A

CARD TYPE	AIRPORT	DATE	FLIGHT NUMBER	AIRCRAFT TYPE	ARRIVAL TIME AT GATE (STOP)	GATE NUMBER	DEPARTURE TIME FROM GATE (ROLLING)	REMARKS
1	XYZ	922						
			PS 111	B727		33A	130710	
			UA 100	DC8S	130800	61		
			TW 207	L101	130925	40		
			PA 1	B747		2	130950	
			AA 416	B747	131355	20		

*A standard card form, IBM electro 888157, is available for punching statements from this form.

PMM - FAA CODING SHEET II-B
AIRCRAFT FLOWRATE - GATES

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Name JOHN DOE
Date 9/22/73 Data Set 999
Day SAT. Page 1 of 1

FIGURE III-3. CODING SHEET II-B

CARD TYPE	AIRPORT	DATE	FLIGHT NUMBER	AIRCRAFT TYPE	COORDINATION FIX	FIRST TIME AT COORDINATION FIX	REMARKS
1	XYZ	922					
			UA100		CRU	125025	
			TW207		PDR	125905	
			AA416		CRU	125650	

*A standard card form, IBM electro 888157, is available for punching statements from this form

PMM - FAA CODING SHEET II-C
AIRCRAFT FLOWRATE - APPROACH AIRSPACE

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8/73
Name JOHN DOE
Date 9/22/73 Data Set 999
Day SAT. Page 1 of 1

FIGURE III-4. CODING SHEET II-C

CARD TYPE	AIRPORT	DATE	FLIGHT NUMBER	AIRCRAFT TYPE	RUNWAY	ARRIVAL TIME (THRESHOLD)	DEPARTURE TIME (ROLL)	QUEUE LENGTH	T & G, ETC.	APPROACH DIST.	COORDINATION FIX	TIME AT COORDINATION FIX	ARRIVAL TIME AT GATE	GATE NUMBER	DEPARTURE TIME FROM GATE
1	XYZ	922													
			UA100	DC8S	1R	130315									
			TW207	L101	1L	130635									
			AA416	B747	1R	130958		2							
			PS111	B727	1R		131115	1							
			PA 1	B747	1R		131240								

*A standard card form, IBM electro 888157, is available for punching statements from this form.

PMM - FAA CODING SHEET II-D

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Date 9/22/73 Name JOHN DOE Data Set 999

Day SAT Page 1 of 1

FIGURE III-5. CODING SHEET II-D

CARD TYPE	AIRPORT	DATE	FLIGHT NUMBER	AIRCRAFT TYPE	ARRIVAL TIME AT GATE (STOP)	GATE NUMBER	DEPARTURE TIME FROM GATE (ROLLING)	REMARKS
1	XYZ	922						
			AA	B707		20		
			AA	B707		21		
			AA	DC10		26		
			AA	B707		28		
			AA	B747		25		
			AA	B747	1315	22		
			AA	DC10	1320	24		
			AA	B707		20	1325	
			AA	B707		21	1329	
			AA	B707	1330	20		
			AA	DC10		26	1335	
			AA	B707		28	1345	

*A standard card form, IBM electro 888157, is available for punching statements from this form

PMM&Co. - FAA CODING SHEET II-E
GATE UTILIZATION/OCCUPANCY

PMM&Co.

8/73
Name John Doe
Date 9/22/73 Data Set 999
Day SAT. Page 1 of 1

FIGURE III-6. CODING SHEET II-E

CARD TYPE	AIRPORT	DATE	AIRCRAFT TYPE (CROSSING OPERATION)	TIME TAXIING AIRCRAFT REACHES CROSSING POINT	AIRCRAFT TYPE (RUNWAY OPERATION)	ARR/DEPARTURE	ARRIVAL/ DEPARTURE TIME (RUNWAY OPERATION)	TIME RUNWAY OPERATION PASSES CROSSING POINT	TIME CROSSING AIRCRAFT BEGINS ROLL	TIME CROSSING AIRCRAFT TAIL CLEARS RUNWAY	AIRCRAFT TYPE (ON RUNWAY)	ARR/DEPARTURE	ARRIVAL/ DEPARTURE TIME (RUNWAY OPERATION)	CROSSING LOCATION	CONTINUE
1	XYZ	922													
			DC 9	015045	B727	A	015100	015115	015120	015145				25	
			B707						015715	015740	DC 8	A	015815		

PMM&Co. - FAA CODING SHEET II-F
RUNWAY CROSSING

PMM&Co.

8/73
Name JOHN DOE
Date 9/22/73 Data Set 999
Day SAT. Page 1 of 1

FIGURE III-7. CODING SHEET II-F

CARD TYPE	AIRPORT	DATE	AIRCRAFT TYPE	LINK NUMBER	TIME AT START OF LINK	TIME AT END OF LINK
1	XYZ	922				
			B707	52	031240	031320
			B747	52	031245	031325
			DC10	52	031251	031330

PMM&Co. - FAA CODING SHEET II-G
TAXI HEADWAYS

PMM&Co.

8/73

Date 9/22/73 Name JOHN DOE

Day SAT. Data Set 999

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FIGURE III-8. CODING SHEET II-G

CODING SHEET II-B
AIRCRAFT FLOW RATE--GATES
FAA Airport Capacity Study

Instructions

1. Tune to ground control frequency.

2. Record airline, flight number, aircraft type, destination gate for arrivals reporting to ground controller.

3. Record arrival time (when aircraft is stopped) at gate from observation and record gate number if not reported earlier from gate assignment map.

4. For departures, record departure time from gates (when aircraft begins moving) and gate number from observation and gate assignment map.

5. Record airline, aircraft type from observation.

6. Record flight number as pilot requests to pushback or requests to taxi on ground control frequency.

7. For general aviation aircraft, record arrival or departure time to or from apron area, aircraft tail number, and aircraft type.

Equipment

1. Digital clock

2. VHF radio or headset to ground control

3. Binoculars

Objective

1. Relating to data collected from Coding Sheet II-D, determine travel times of aircraft on airfield.

FIGURE III-9. CODING SHEET II-B INSTRUCTIONS

CODING SHEET II-C
AIRCRAFT FLOW RATE--APPROACH AIRSPACE
FAA Airport Capacity Study

Instructions

1. Tune to approach control frequency.
2. Record airline, flight number, arrival coordination fix, and initial arrival time over arrival coordination fix.
3. Record other arrivals not crossing arrival coordination fix.

Equipment

1. Radar Scope (hopefully, ARTS III)
2. Headset
3. Approach Control Map
4. Clock, if no ARTS III

Objective

1. Obtain aircraft arrival times in the terminal area airspace.
2. Obtain 15-minute demand on the system.
3. Relating to data collected from Coding Sheet II-D, determine the travel times from entry fix to runway threshold.

FIGURE III-10. CODING SHEET II-C INSTRUCTIONS

CODING SHEET II-D
AIRCRAFT FLOW RATE--RUNWAYS
FAA Airport Capacity Study

Instructions

1. Tune to local control frequency.

2. Record all arrival and departure aircraft on runway.

3. Arrivals--record airline, flight number, aircraft type, runway number, and arrival time over threshold in Greenwich mean time (GMT).

4. Departures--record airline, aircraft type, flight number, runway number, and time in GMT that aircraft starts to roll on runway for takeoff.

5. After each operation, record departure queue length, if any.

6. For touch-and-go's, low approaches, etc., record "T" for touch-and-go's, "L" for low approaches, and "M" for missed approaches in appropriate column.

7. Approach distance--for aircraft turning inside outer marker on final approach to runway, record final approach distance from threshold.

Equipment

1. Digital clock

2. VHF radio or headset to local control

3. Binoculars, if necessary

Objective

1. Obtain flow rate of all arrivals and departures on runways.

2. Obtain indication of degree of saturation.

FIGURE III-11. CODING SHEET II-D INSTRUCTIONS

Coding Sheet II-D (cont.)

3. Relating to data collected from Coding Sheet IIC, determine the travel times of aircraft from entry to over the runway threshold.

4. Relating to data collected from Coding Sheet IIB, determine the travel times of arrival aircraft from over the threshold to taxi onto gate, and for departing aircraft from gate push-back to roll on runway.

FIGURE III-11. CODING SHEET II-D INSTRUCTIONS

CODING SHEET II-E
GATE UTILIZATION/OCCUPANCY
FAA Airport Capacity Study

Instructions

1. Tune to ground control frequency.

2. Record gate numbers which are being occupied by aircraft.

3. Record start-up time of data collection for each occupied gate.

4. For arrivals, record aircraft type, airline, flight number, arrival time at gate in GMT, and gate number.

5. For departures, record airline, flight number, aircraft type, departure time from gate, and departure gate.

6. If parking position of surveyed aircraft is in a different position than is normal for that gate, note in the remarks column.

Equipment

1. Digital clock

2. VHF radio or headset to ground control

3. Binoculars, if necessary

Objective

1. Obtain gate utilization information during peak periods.

2. Obtain gate occupancy times during peak periods.

FIGURE III-12. CODING SHEET II-E INSTRUCTIONS

CODING SHEET II-F
RUNWAY CROSSING
FAA Airport Capacity Study

Instructions

1. Observe runway/taxiway crossing point in airfield.

2. For separation between arrival or departure aircraft and aircraft crossing active runway:

   - Record time taxiing aircraft reaches crossing point and aircraft type.
   - Record arrival or departure aircraft type and time over threshold or roll.
   - Record time arrival or departure aircraft passed crossing point.
   - Record time crossing aircraft begins to roll across runway.
   - Record time crossing aircraft tail clears runway corridor.
   - Record crossing location.

3. For separation between aircraft crossing active runway and arrival or departure aircraft:

   - Record time aircraft rolls across runway and aircraft type.
   - Record time crossing aircraft clears runway corridor.
   - Record following arrival or departure aircraft type, type of operation, and time of operation (roll time for departures and over the threshold time for arrivals).
   - Record crossing location.
   - For continuation of data, record a "1" in column 76 and proceed to record data on following line.

FIGURE III-13. CODING SHEET II-F INSTRUCTIONS

Coding Sheet II-F (cont.)

Equipment

1. Binoculars, if necessary

2. Digital clock

3. Stopwatch

4. Airfield network map

Objective

1. Obtain separation between arrival or departure aircraft and aircraft crossing active runway.

2. Obtain separation between aircraft crossing active runway and arrival and departure aircraft.

3. Determine taxiing time by aircraft type to cross active runway.

FIGURE III-13. CODING SHEET II-F INSTRUCTIONS

CODING SHEET II-G
TAXI HEADWAYS
FAA Airport Capacity Study

Instructions

1. Record consecutive operations of taxiing aircraft over a link segment.

2. Record aircraft type, time aircraft is at beginning of link, and time aircraft is at end of link.

Equipment

1. Binoculars, if necessary

2. Digital clock

3. Stopwatch

4. Airfield network map

Objective

1. Obtain headways of taxiing aircraft during unrestricted conditions.

FIGURE III-14. CODING SHEET II-G INSTRUCTIONS

It should be noted that on Coding Sheet II-D, information is recorded on the existence of an aircraft departure queue. This information is used as a check that the data collected during the survey period represent the high activity conditions desired for model comparison.

Data Collection in the Field. On the first day at each data collection airport, an orientation meeting was held with FAA air traffic control personnel. Following this meeting, data collection efforts were scheduled for both peak and off-peak activity periods. The duration of the peak and off-peak periods were determined from hourly air traffic activity counts obtained during the presurvey visits and from conversations with air traffic control personnel.

The data collected during the peak period were used for the validation of the runway capacity models, gate capacity models, and delay models. The off-peak period data were used to obtain data on the normal (or undelayed) aircraft travel times on the airfield for the validation of the delay model.

In total, some 30,000 data observations were recorded during validation data collection in Phase II. A summary of the data collected is presented in Table III-2.

IFR Data Contingency. In order to ensure that sufficient IFR data were available for validation, an intensive effort was made to discover and obtain data previously collected from other projects. A major source of IFR data was the U.S. Department of Transportation, Transportation Systems Center (TSC). The data, from a TSC study performed during February and March 1973 were in the form of 16mm films of the ASDE display and tape recordings of air traffic control communications at Chicago O'Hare International Airport. As noted in Table III-2, some 1,700 data observations were made from the ASDE and tape recordings (i.e., ORD-ASDE). The data recording procedure for validation consisted of two steps: (1) viewing the films to record aircraft arrival and departure times on runways, taxiway crossing characteristics, time separations between aircraft, taxiing headways between aircraft, and arrival runway occupancy times; and (2) listening to the tape recordings to determine the flight numbers of operations recorded from the film. The flight numbers were then matched with an IFR arrival and departure listing to determine the aircraft type for each operation.

Table III-2

DATA SUMMARY
NUMBER OF OBSERVATIONS RECORDED
FAA Airport Capacity Study

Airport	Number of Observations Recorded on Sheet Number						
	II-B	II-C	II-D	II-E	II-F	II-G	Total
BOS	1,635	1,223	2,360	240	40	65	5,563
SNA	1,015	--	3,922	34	22	--	4,993
SMO	--	--	2,217	--	--	--	2,217
ORD	2,899	2,329	5,522	485	--	38	11,273
ORD-ASDE	--	--	1,483	--	62	234	1,779
DAL	1,843	--	2,521	244	14	42	4,664
Total	7,392	3,552	18,025	1,003	138	379	30,489

Data Reduction

Figure III-15 illustrates the data reduction process used in the validation of the capacity and delay models. The data reduction process was conducted in parallel with the data collection to maximize study efficiency. After each day of data collection in the field, data recorded on Coding Sheets II-B and II-C were transferred to Coding Sheet II-D. In addition, the data sheets were checked daily in the field for legibility, consistency, and conformance to rules to ensure that the data would be properly interpreted by the keypuncher. Duplicate copies were made of all data sheets for record purposes; the original data sheets were used for keypunching and verification.

After all data for an airport were keypunched, the punched cards were loaded and stored in a computer library filing system. Then, the data were retrieved from the file and output listings were produced. The listings were reviewed by the project team and checked for possible errors. All errors were then corrected and replaced in the filing system. Figure III-16 illustrates a typical listing produced for data verification.

Specifications for data reduction computer programs were established immediately after the data forms were developed. As a result, computer programming commenced during the data collection effort. Computer programs were developed for data reduction as well as for data preparation in support of validation. Data reduction also included the utilization of programs developed in Phase I.

Three major computer programs were developed in Phase II for the reduction of data for validation comparison:

- Aircraft Flow Rate - Runways
- Aircraft Flow Rate - Gates
- Travel Time and Delay

Aircraft Flow Rate--Runways. The output from this computer program is the reduced field data for validation comparison with the output of the runway capacity models. The computer program processes all data recorded on Coding Sheet II-D. The program output is presented for 15-minute segments consisting of two tables: (1) a listing of each operation; and (2) a aircraft flow summary. A sample of the computer program output is presented in Figures III-17 and III-18.

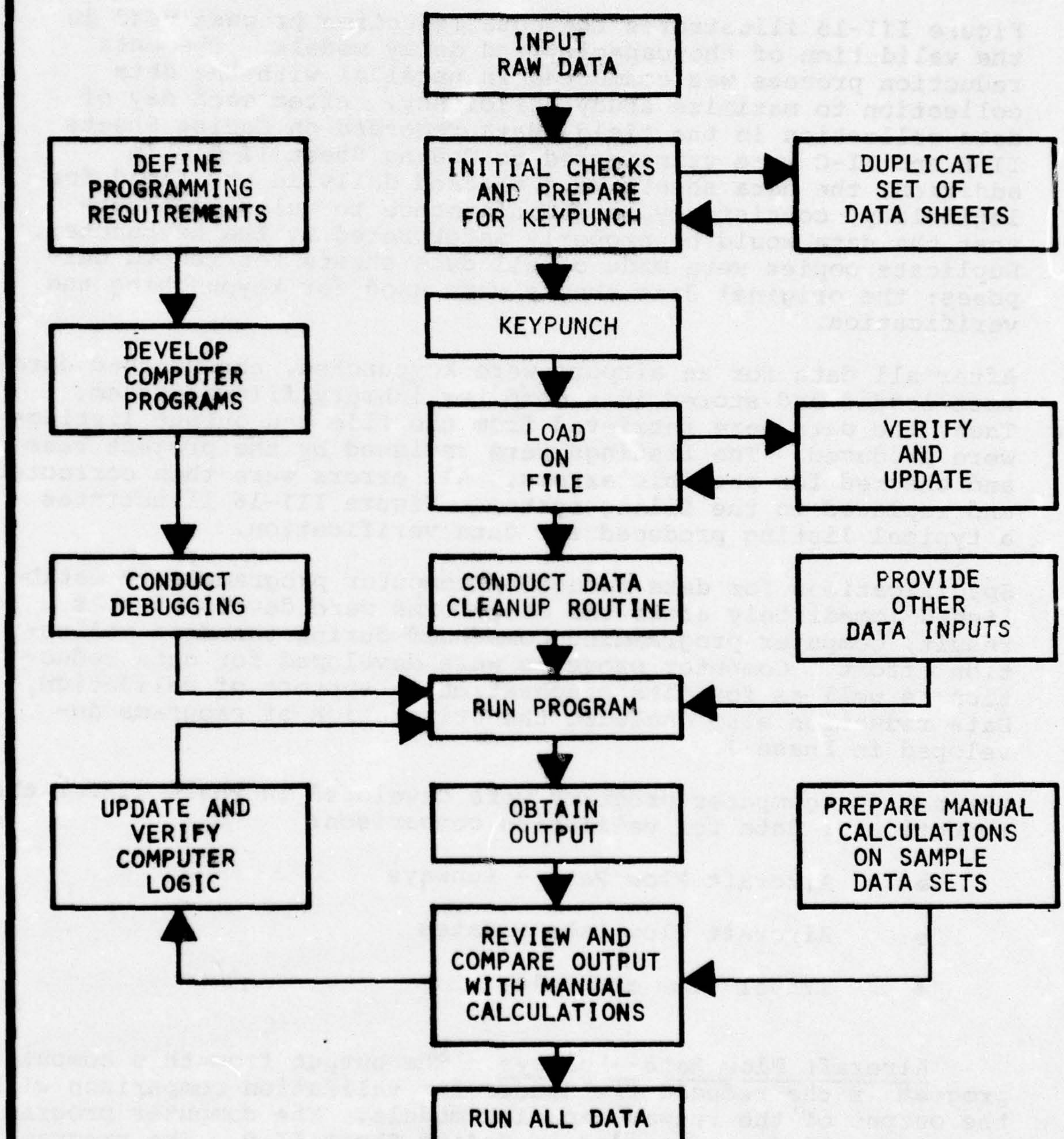


FIGURE III-15. DATA REDUCTION PROCESS

```
1 ORD 025 UA276 DC8  322        194228 3                                   D407
1 ORD 025 UA224 DC8  322        194429 3                       F 1 192920  D407
1 ORD 025 AA332 B727 322        194942                         K 8 192950  D407
1 ORD 025 NW217 B727 272 194416        4   BAE 193035 194644 D10           D407
1 ORD 025 UA362 B737 322        194507 2                       F 4 193400  D407
1 ORD 025 UA533 B737 272 194603            WSK 192900                      D407
1 ORD 025 NC294 CV58 272 194742        2   BAE 193405                      D407
1 ORD 025 UA235 B727 272 194916        2   BAE 193325 195340 F 1           D407
1 ORD 025 UA426 DC8  322        194637 1                                   D407
1 ORD 025 UA394 B727 322        194758 1                                   D407
1 ORD 025 UA142 DC10 322        195328 0                       F 2 193745  D407
1 ORD 025 NW356 B727 272 195109        2   WSK 193315                      D407
1 ORD 025 NW535 B727 322        195255 1                                   D407
1 ORD 025 TW336 B727 272 195237        2                                   D407
1 ORD 025 UA223 B727 272 195432        2   BAE 193815                      D407
1 ORD 025 TW234 DC9  272 195558        2   WSK 193545                      D407
1 ORD 025 AA197 DC10 322        195509 1                       K11 194255  D407
1 ORD 025 AL842 DC9  322        195631 2                                   D407
1 ORD 025   70P 2ENG 35         195410 0                                   D407
1 ORD 025 UA705 B737 272 195746        2   BAE 193935 195905 F 4           D407
1 ORD 025 BA451 2ENG 272 195941        2   WSK 193530                      D407
1 ORD 025 NC102 CV58 322        195718 2                                   D407
1 ORD 025 NC808 CV58 322        195753 1                       H 2 194610  D407
1 ORD 025 UA321 B727 272 200124        2   BAE 194140                      D407
1 ORD 025 NW717 B727 322        200138 2                       D 4 195000  D407
1 ORD 025 TW339 B727 322        200156 1                       G 6 195020  D407
1 ORD 025 WI534 2ENG 272 200302        1   BAE 194140                      D407
1 ORD 025 TW394 B727 322        200415 0                       G 3 194755  D407
1 ORD 025 UA155 DC8H 272 200428        1   BAE 194325 200605 F11           D407
1 ORD 025 TW771 B747 272 200611        1   BAE 194350 200937 B 1           D407
1 ORD 025 TW284 707H 322        200633 1                                   D407
1 ORD 025 UA765 DC8H 322        200509 1                                   D407
1 ORD 025 AA318 B707 322        200743 0                       K 9 195515  D407
1 ORD 025 TW 02 B707 272 200837        2                                   D407
1 ORD 025 OL727 DC9  272 201007        3                                   D407
1 ORD 025 N52MC 2ENG 272 201155        2   PLT 195120                      D407
1 ORD 025 N304J GJET 322        201100 2                                   D407
1 ORD 025 UA317 B727 272 201259        2   BAF 195255 201430 F 9           D407
1 ORD 025 UA280 DC9  272 201407        2              201612 F 6           D407
1 ORD 025 NW 18 707H 322        201221 3                                   D407
1 ORD 025 AA274 B727 322        201317 4                       H 2 195850  D407
1 ORD 025 AA352 B727 322        201419 4                       H 1 200115  D407
1 ORD 025 OL548 DC9  322        201601 3                       H 8 200130  D407
1 ORD 025 AA135 B707 272 201539        3   BAE 195810                      D407
1 ORD 025 AA202 DC8H 322        201641 2                       K 5 195745  D407
1 ORD 025 AA526 B727 322        201811 3                       K 2 195825  D407
1 ORD 025 WI542 2ENG 272 201755        3                                   D407
1 ORD 025 AA220 707H 322        201923 2                       H 3 200500  D407
1 ORD 025 N  27 DC3  322        202243 2 I                                 D407
1 ORD 025 AA307 B727 272 202042        2   BAF 200715 202429 H 2           D407
1 ORD 025 AA624 B727 322        202058 1                                   D407
1 ORD 025 AA234 B727 272 202217            WSK 200745                      D407
1 ORD 025 NC185 DC9  322        202450 1                                   D407
1 ORD 025 NC 17 CV58 322        202455 0                       H 7 201110  D407
1 ORD 025 ON031 DC10 272 202441        2   BAF 201005                      D407
1 ORD 025 N302  2ENG 36         202308 1                                   D407
1 ORD 025 N6127 2ENG 272 202843        2   PNO 200740                      D407
1 ORD 025 LH475 707H 322        202909 2                                   D407
1 ORD 025 FDF3  GJET 322        203058 3                                   D407
```

FIGURE III-16. COMPUTER LISTING OF DATA

AIRCRAFT FLOW, RUNWAYS, LISTING FOR 15-MINUTE PERIOD (M = 9)

0	1	2	3	4	5	6	7
AIRCRAFT SEQUENCE NO. K	FLIGHT NUMBER	AIRCRAFT CLASS	RUNWAY	ARRIVAL TIME (THRESHOLD)	DEP. TIME (ROLL)	OPERATION	PERCENT SATURATION FLOW RATE
0				161500	161500		100
1	MVA24	B	27R	161501	0	A	100
2	NW443	C	32R	0	161537	D	100
3	XL611	C	27R	161610	0	A	100
4	AA234	C	32R	0	161621	D	100
5	UA920	C	32R	0	161709	D	100
6	NW716	C	32R	0	161748	D	100
7	TW771	C	27R	161851	0	A	100
8	UA129	C	32R	0	161913	D	100
9	AA828	C	27R	162034	0	A	100
10	NW440	C	32R	0	162040	D	100
11	UA247	C	32R	0	162128	D	100
12	W1967	B	32R	0	162142	D	100
13	SX825	B	27R	162238	0	A	100
14	UA343	D	32R	0	162248	D	100
15	AA 66	D	27R	162352	0	A	100
16	OZ986	C	27R	162522	0	A	100
17	UA403	C	32R	0	162533	D	100
18	N1870	B	36	0	162601	D	100
19	NC572	C	27R	162658	0	A	100
20	NW442	C	27R	162749	0	A	100
21	AA104	C	32R	0	162858	D	92
22	CO 40	C	27R	162947	0	A	65

NOTE - DEFAULT TIME WAS USED 0 TIMES.

FIGURE III-17. DETAILS OF AIRCRAFT FLOW ON RUNWAYS

SUMMARY OF AIRCRAFT FLOW, RUNWAYS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
				NUMBER OF AIRCRAFT BY CLASS				PERCENT MIX				NUMBER OF OPERATIONS				PERCENT OPERATIONS			AVE PERCENT SATURATION FLOW
AIRPORT	DATE	RUNWAY	TIME	A	B	C	D	A	B	C	D	TOTAL	ARRIVAL	DEPARTURE	T-G	ARRIVAL	DEPARTURE	T-G	RATE
ORD	026	27R	161500-163000	0	2	4	4	0	20	40	40	10	10	0	0	100	0	0	99.5
ORD	026	32L	161500-163000	0	1	8	2	0	9	73	18	11	0	11	0	0	100	0	76.3
ORD	026	36	161500-163000	0	1	0	0	0	100	0	0	1	0	1	0	0	100	0	77.4
		TOTALS		0	[illegible]	12	6	0	14	55	27	22	10	12	0	45	55	0	99.0

FIGURE III-18. SUMMARY OF AIRCRAFT FLOW ON RUNWAYS

As shown in Figure III-17, the first table lists each operation by flight number, aircraft class, runway, arrival or departure time, and type of operation (i.e., arrival, departure, or touch-and-go). In addition, percent saturation is computed which represents a measure of the degree to which the activity level approached capacity. The procedure for computing percent saturation is described in a subsequent part of this chapter.

As shown in Figure III-18, the second table presents the aircraft mix, the type of operation and average saturation by runway for each 15-minute interval.

Aircraft Flow Rate--Gates. The output from this computer program is the reduced field data needed for validation comparison with the output of the gate capacity model. The computer program processes all the data recorded on Coding Sheet II-E. In addition to the data processed from Coding Sheet II-E, the total number of gates under observation and gate identification numbers are required inputs of the program. The program output is presented for 15-minute segments consisting of two tables: (1) a listing of each operation; and (2) an aircraft flow summary. A sample of the computer program output is presented in Figures III-19 and III-20.

As shown in Figure III-19, the first table lists each operation in a similar format to Coding Sheet II-E. In addition, gate occupancy time for each departing aircraft (which arrived during the study period), number of gates occupied, and percent saturation are presented. As shown in Figure III-20, the second table presents the average percent saturation, the number of arrivals, the number of departures, and the aircraft mix for each 15-minute interval.

Travel Times and Delay. The output from this computer program is the reduced field data needed for validation comparison with the output of the delay model. The computer program processes the data recorded on Coding Sheet II-D. In addition to the data processed from Coding Sheet II-D, normal travel times are a required input of the program (normal travel times are described in a subsequent part of the chapter). The program output is presented for 15-minute segments consisting of three tables: (1) a listing of delay and travel time for each operation; (2) a summary of arrival and departure delays by runway operation; and (3) a summary of travel times by runway operation. A sample of the computer program output is presented in Figures III-21 through III-23.

AIRCRAFT FLOW GATES, LISTING OF OPERATIONS IN 15-MINUTE PERIOD (M = 6)

DATA SET = 405 AIRPORT = ORD DATE = 024 NO. OF GATES UNDER OBSERVATION = 16

0	1	2	3	4	5	6	7	8
K	FLIGHT NUMBERS	A/C TYPE	TIME (LOCAL)	OPERATION	GATE OCCUPANCY TIME (MIN)	GATE NUMBER	NO. OF GATES OCCUPIED	PERCENT SATURATION FLOW RATE
0			145000				7	43.0
1	UA	B727	145038	A	0.0	F1	8	50.0
2	UA	B727	145241	A	0.0	E7	9	56.0
3	UA	B727	145505	D	68.7	E3A	8	50.0
4	UA	DC 8	145510	D	0.0	F11	7	43.0
5	UA	B727	145850	D	40.4	E2	6	37.0
6	CO	B727	150242	D	79.7	D11	5	31.0
7	UA	B727	150331	A	0.0	F1	6	37.0

FIGURE III-19. DETAILS OF AIRCRAFT FLOW ON GATES

SUMMARY OF AIRCRAFT FLOW GATES

DATA SET = 405

0	1	2	3	4	5	6	7	8	9	10	11	12
				OPERATIONS			AVERAGE PERCENT SATURATION FLOW RATE	MIX ARRIVALS + DEPARTURES + SOG				TOTAL NO. OF GATES UNDER OBSERVATION
N	AIRPORT	GATE	TIME	ARRIVALS	DEPARTURES	STAY-ON-GATE (SOG)		A	B	C	D	
0	ORD	120	145000-150500	3	4	3	43.3	0	0	7	3	16

FIGURE III-20. SUMMARY OF AIRCRAFT FLOW ON GATES

LISTING OF 15-MINUTE DELAY DATA

DATE = 101 DATA SET = 417 PERIOD M = 4 AIRPORT = ORD

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
														TRAVEL TIME		
K	RNWAY	AIR-CRAFT CLASS	OBSVD ARRVL TIME (FIX)	FIX	OBSVD ARRVL THRHD	OBSVD ARRVL TIME GATE	OBSVD DPART TIME ROLL	OBSVD DPART TIME GATE	GATE	EXPTD READY DP OR GT TM	DPART GRND DELAY (MIN)	ARRVL GRND DELAY (MIN)	ARRVL AIR DELAY (MIN)	ACT DEP GRND (MIN)	ACT ARRVL GRND (MIN)	ACT ARRVL AIR (MIN)
0							152500									
1	32R	B	0		0	0	152543	0		0	0.00	0.00	0.00	0.00	0.00	0.00
2	27R	C	151320	WSK	152642	0	0	0		0	0.00	0.00	1.70	0.00	0.00	13.37
3	32L	B	151540	PNO	152716	153200	0	0	F10	153028	0.00	1.53	0.00	0.00	4.73	11.60
4	27R	C	151440	WSK	152831	155043	0	0	F 8	153204	0.00	18.65	2.19	0.00	22.20	13.85
5	32R	C	0		0	0	152849	151730	D10	152405	4.73	0.00	0.00	11.32	0.00	0.00
6	32L	C	151745	PIT	152854	153648	0	0	H 2	153446	0.00	2.05	2.25	0.00	7.90	11.15
7	27R	B	151605	HAE	153015	0	0	0		0	0.00	0.00	3.17	0.00	0.00	14.17
8	32R	D	0		0	0	153028	0		0	0.00	0.00	0.00	0.00	0.00	0.00
9	27R	C	151905	BAE	153157	0	0	0		0	0.00	0.00	2.87	0.00	0.00	12.87
10	32R	D	0		0	0	153215	152125	D 8	152900	3.25	0.00	0.00	10.83	0.00	0.00
11	32R	B	0		0	0	153309	152620	A 2	152940	3.48	0.00	0.00	6.82	0.00	0.00
12	32L	C	152315	CGT	153338	154016	0	0	H11	153912	0.00	1.07	1.30	0.00	6.63	9.88
13	27L	C	0		0	0	153340	152740	H10	153331	.15	0.00	0.00	6.00	0.00	0.00
14	27R	C	151850	WSK	153419	154418	0	0	F 7	153936	0.00	4.70	3.82	0.00	9.98	15.48
15	32R	D	0		0	0	153446	152120	D 6	152908	5.55	0.00	0.00	13.43	0.00	0.00
16	27R	D	152130	WSK	153645	0	0	0		0	0.00	0.00	2.83	0.00	0.00	15.25
17	32R	C	0		0	0	153658	152940	F10	153556	1.03	0.00	0.00	7.30	0.00	0.00
18	32L	B	0		153659	0	0	0		0	0.00	0.00	0.00	0.00	0.00	0.00
19	32R	D	0		0	0	153807	153005	F 6	153735	.55	0.00	0.00	8.05	0.00	0.00
20	27R	B	152750	BAE	153911	0	0	0		0	0.00	0.00	.35	0.00	0.00	11.35
21	32R	D	0		0	0	153927	153130	K 9	153642	2.75	0.00	0.00	7.95	0.00	0.00
22	32L	D	152920	VLY	153931	154634	0	0	B 2	154394	0.00	3.50	.18	0.00	7.05	10.18

FIGURE III-21. DETAILS OF AIRCRAFT DELAY AND TRAVEL TIME

DELAY SUMMARY

AIRPORT = ORD   DATE = 101   DATA SET = 417

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		OPERATIONS																AVERAGE DEPARTURE	SAMPLE	AVERAGE ARRIVAL	SAMPLE SIZE	AVERAGE ARRIVAL	SAMPLE SIZE
		ARRIVALS					DEPARTURES					TOUCH-AND-GO					GRAND	DELAY	SIZE	GROUND	ARRIVALS	AIR	ARRIVALS
M	RUNWAY	A	B	C	D	TOTAL	A	B	C	D	TOTAL	A	B	C	D	TOTAL	TOTAL	(MIN)	DEPARTURE	DELAY	(GROUND)	DELAY	(AIR)
4	32R	0	0	0	0	0	0	2	2	5	9	0	0	0	0	0	9	3.1	7	0.0	0	0.0	0
4	27R	0	2	4	1	7	0	0	0	0	0	0	0	0	0	0	7	0.0	0	11.7	2	2.4	7
4	32L	0	2	2	1	5	0	0	0	0	0	0	0	0	0	0	5	0.0	0	2.0	4	1.2	3
4	27L	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	.1	1	0.0	0	0.0	0
TOTAL		0	4	6	2	12	0	2	3	5	10	0	0	0	0	0	22	2.7	8	5.2	6	2.1	10

FIGURE III-22. DELAY SUMMARY

TRAVEL TIME SUMMARY

AIRPORT = ORD DATE = 101 DATA SET = 417

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		OPERATIONS																AVERAGE DEPARTURE	SAMPLE	AVERAGE ARRIVAL	SAMPLE SIZE	AVERAGE ARRIVAL	SAMPLE SIZE
		ARRIVALS					DEPARTURES					TOUCH-AND-GO					GRAND	TRAVEL	SIZE	GROUND	ARRIVALS	AIR	ARRIVALS
M	RUNWAY	A	B	C	D	TOTAL	A	B	C	D	TOTAL	A	B	C	D	TOTAL	TOTAL	(MIN)	DEPARTURE	TRAVEL	(GROUND)	TRAVEL	(AIR)
4	32R	0	0	0	0	0	0	2	2	5	9	0	0	0	0	0	9	9.4	7	0.0	0	0.0	0
4	27R	0	2	4	1	7	0	0	0	0	0	0	0	0	0	0	7	0.0	0	16.1	2	13.8	7
4	32L	0	2	2	1	5	0	0	0	0	0	0	0	0	0	0	5	0.0	0	6.6	4	10.7	4
4	27L	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	6.0	1	0.0	0	0.0	0
TOTAL		0	4	6	2	12	0	2	3	5	10	0	0	0	0	0	22	9.0	8	9.8	6	12.6	11

FIGURE III-23. TRAVEL TIME SUMMARY

In this computer program, delay is defined as the difference in time between normal travel time and actual travel time. Delays are separated into ground delays and air delays. Ground delays are computed by subtracting the normal travel time from the actual travel time of each aircraft between the threshold and the gate. Air delays were computed by subtracting the normal travel time from approach fix to runway threshold from the actual observed travel time between the same two points.

Percent Saturation. As noted previously, percent saturation is an output of two of the data reduction programs (i.e., aircraft flow rate--runways; aircraft flow rate--gates).

The definition of hourly capacity used in the project implies that capacity-level flow rates occur when there is a continuous demand for service.* Therefore, for validation it is essential that the model outputs be compared with the observed flow rate when there is a continuous demand, or its equivalent.

At very few airports is there a continuous demand for service for any length of time. As a result, a measure of the degree of saturation was developed to determine the proportion of time that a continuous demand occurred within a designated period of time. This measure is called percent saturation and is expressed in the following formula for runway capacity and gate capacity:

Runway Capacity.

$$PS_k = \text{Min } [100,\ 100T(x,y,i,j)/(T_{k+1} - T_k)]$$

where

PS_k = percent saturation between k^{th} and k+1 aircraft

x = type of operation (arrival, departure, or touch-and-go) for k^{th} aircraft

y = type of operation for $k^{th}+1$ aircraft

i = aircraft class of k^{th} aircraft

j = aircraft class of $k^{th}+1$ aircraft

---

*The existence of a queue waiting to use an airfield component is evidence of continuous demand for service.

$T(x,y,i,j)$ = the minimum accepted time separation on the threshold between the operations k and k+1

T = observed time

To calculate percent saturation of runway capacity, it is necessary to identify the minimum acceptable time separation between aircraft. Minimum separations were based on Phase I and II data.

The computation of PS_k is performed in reference to previous operations on the same and all dependent runways. If a departure queue was observed and noted in the data sheets, it is assumed in the program that there is an aircraft waiting to be serviced and that the runway was operating at capacity. Therefore, the percent saturation between operations is 100.

Gate Capacity.

$$PS_k = \frac{NGO_k}{NG} \times 100$$

where

PS_k = percent saturation for period of time between operations k and k+1

NG = number of gates

NGO_k = number of gates occupied after operation k

For either the runways or the gates, the following formula is used to determine the average percent saturation during a 15-minute period.

$$PS_m = \frac{\sum_{K=0}^{Kmax-1} (T_{k+1} - T_k)PS_k + (T_o + 900 - T_{kmax})PS_{kmax}}{900}$$

where

PS_m = average percent saturation for m^{th} 15-minute perio

T_o = time at beginning of 15-minute period

T_{kmax} = time of last operation in 15-minute period

PS_{kmax} = the percent saturation for the last operation in the 15-minute period.

Normal Travel Times. Data recorded on Coding Sheet II-D during off-peak periods were compiled and used as input for a program to produce travel times and delay. A data reduction program is used to produce distributions of undelayed or normal travel times in graphical form for each aircraft class and for designated routings (i.e., gate number to runway, runway to gate, etc.). A typical plot of normal travel time data is illustrated in Figure III-24. In this figure, a sample of arrival travel times for airborne aircraft observed at Chicago O'Hare International Airport is presented.

Verification of Data Reduction Programs. Manual calculations of sample data sets were made to verify the output from each of the programs. This debugging process was used when the computer programs were ready for final test runs. If the output could not be verified, the computer logic was reviewed and updated. Once the output was verified, individual data sets were run for all airports.

Further Specification of Validation

Based on a review of the collected and analyzed data, it was determined that there were sufficient data for validation of the various models as follows:

- Validation of Runway Capacity Model--Chicago O'Hare International Airport in VFR and IFR; Dallas Love Field in VFR and IFR; and Orange County Airport in VFR.

- Validation of Gate Capacity Model--Chicago O'Hare International Airport; and Dallas Love Field.

- Validation of Delay Model--Chicago O'Hare International Airport; Dallas Love Field; Orange County Airport.

Data Assembly for Model Runs

Runway and Gate Capacity Models. Two steps were involved in the selection of appropriate data for the validation of the runway and gate capacity models. The first step was to select data sets at each airport which satisfied three criteria: (1) similar runway operating strategies; (2) high demand levels; and (3) similar weather (i.e., ceiling and visibility) conditions. Computer processing of the selected data sets resulted in summaries by 15-minute intervals for the following items:

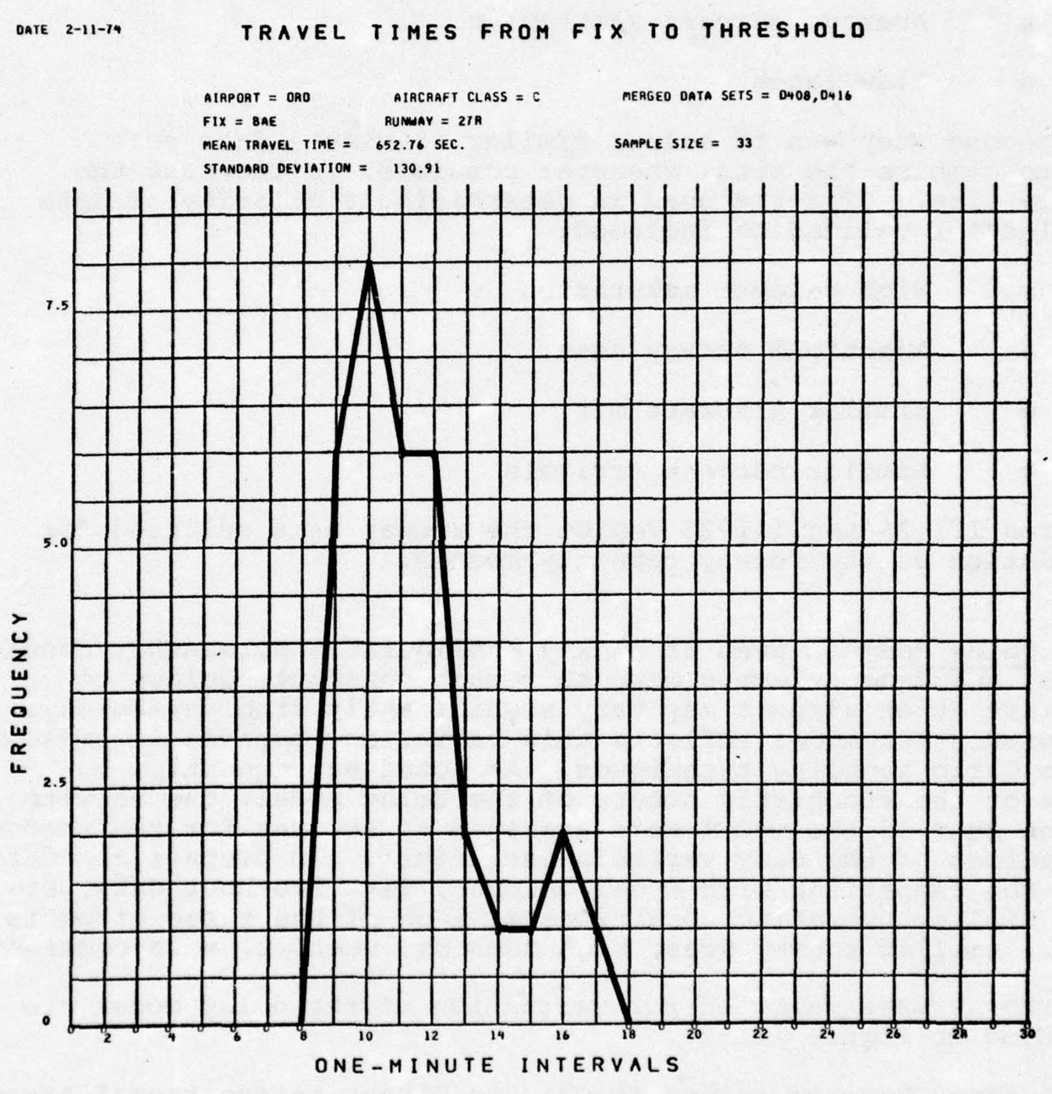


FIGURE III-24. TRAVEL TIME PLOT

- Number of operations on each runway by aircraft type and by operation type
- Aircraft mix
- Average percent saturation
- Flow rates

The second step was to select similar 15-minute data sets and to combine the sets, whenever possible, to increase the sample size. Criteria used in determining similarity of data samples for validation included:

- High percent saturation
- Identical runway uses
- Similar aircraft mix
- Similar percent arrivals

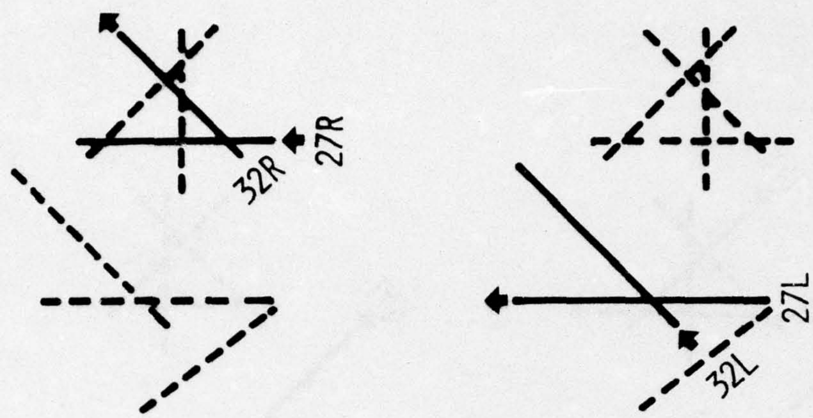
Figures III-25 and III-26 depict the runway uses selected for validation of the runway capacity models.

Delay Model. Even if runway configurations, weather conditions, and demand levels were to remain constant, delays to aircraft at an airport may vary significantly from day-to-day. The simulation model reflects this variation, because it employs Monte Carlo sampling techniques. As noted subsequently, because of the stochastic nature of the delay model, the results of ten runs of the model were averaged to account for the random deviations of the many variable parameters. To prepare the data base for comparison with model outputs, five two-hour data sets with similar operating conditions at each of the three airports (i.e., similar runway uses, high demands, weather) were combined.

The runway uses selected for validation of the delay model are depicted in Figure III-27.

Model input data collected at Chicago O'Hare International Airport, Dallas Love Field, and Orange County Airport were used whenever possible for the validation process. The following procedure was used in establishing key schedule input data:

- Based on 15-minute flow rates, interarrival and interdeparture time intervals were generated stochastically using a geometric distribution.

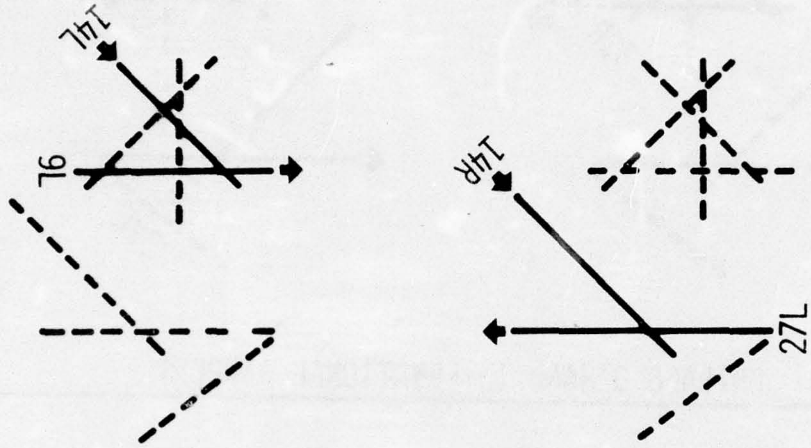


CHICAGO O'HARE INTERNATIONAL AIRPORT

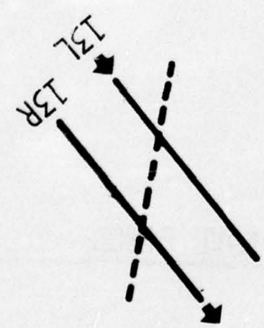
DALLAS LOVE FIELD

ORANGE COUNTY AIRPORT

FIGURE III-25. RUNWAY USE CONFIGURATIONS - VFR CAPACITY VALIDATION

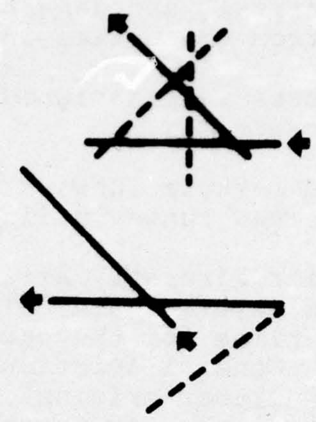


CHICAGO O'HARE INTERNATIONAL AIRPORT

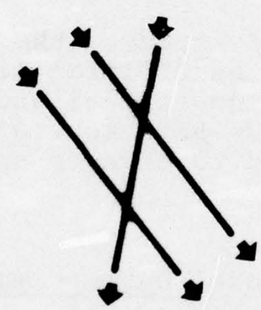


DALLAS LOVE FIELD

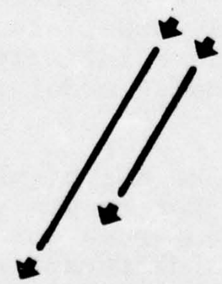
FIGURE III-26. RUNWAY USE CONFIGURATIONS - IFR CAPACITY VALIDATION



CHICAGO O'HARE INTERNATIONAL AIRPORT



DALLAS LOVE FIELD



ORANGE COUNTY AIRPORT

FIGURE III-27. RUNWAY USE CONFIGURATIONS - DELAY VALIDATION

- "Scheduled" arrival and departure times were established from these time intervals.

- Aircraft classes were assigned based on the observed aircraft mix.

- Arrival and departure runways were assigned based on observed runway utilization data.

- For air carrier aircraft, arrival and departure times were matched using typical gate service times for the particular aircraft class. General aviation aircraft were assumed to be either originating departures, terminating arrivals, or touch-and-go operations.

- Gates were assigned based on observed gate utilization data, using a gate schedule plot. General aviation aircraft were assumed to originate or terminate from basing areas.

At Chicago O'Hare International Airport, the procedure above was supplemented by data from the Official Airline Guide (OAG) to provide further information on arrival and departure times as well as aircraft classes. In addition, airline identifiers from the OAG listings were used to develop appropriate gate assignment information.

Model Runs and Comparison of Model Outputs with Field Data

The validation process was performed in cycles. Runs of the capacity models were made, and the model logic and input data were refined until model outputs were within ±15% of the observed validation data. The inputs from these runs that are common to the capacity and the delay models were then used for the delay model runs. The delay model also requires other input data (e.g., link data, route data) which were also developed. A detailed description of the delay model inputs are contained in a companion report.[2]

An important consideration in the use of the delay model is the number of runs made to account for random variations. In order to determine a suitable number of runs for the validation of the model, runs were made using different random number "seeds." The effect of random variations is sufficiently dampened after ten runs of the model. Consequently, ten runs of the model were used in the validation process and the average results were compared with the field data for the five two-hour data sets described previously.

Runs of the delay model were made, and the model logic and input data for the delay model were refined until model outputs were within ±15% of the observed validation data. A check was then made to determine if the input data for the capacity models had been significantly changed. In all cases, changes were not significant.

Final Comparison of Model Results with Field Data

The final step in the validation process for the capacity models consisted of comparing observed flow rates in the field with the outputs from capacity models.

Results of these final comparisons of the runway and gate capacity models are shown on Tables III-3 and III-4 and in Figures III-28 and III-29. Table III-3 demonstrates that the difference between observed and calculated runway capacities (i.e., flow rates) range from -12% to +13% with an average difference of +7%. Table III-4 shows the difference in gate capacities (i.e., flow rates) for observed and calculated values ranging between -15% and +13% with an average difference of -3%.

The final step in the validation process for the delay model involved comparing arrival and departure travel times observed in the field with the outputs from the delay model. Results of the delay model validation process for each of the three airports are shown in Figure III-30 and Table III-5. Table III-5 sets forth the difference between observed and calculated travel times ranging from -7% to +13% with an average difference of +3%.

Conclusion

Validation of the runway and capacity models and the delay model has been successfully demonstrated within the desired tolerances of ±15%. Consequently, the models developed in the project are appropriate for use in the preparation of the Airfield Capacity and Delay Handbook for FAA.

All field data, related data reduction summaries, capacity and delay model runs, and comparisons developed as part of the validation have been transmitted to the FAA.

Table III-3

RUNWAY CAPACITY MODEL VALIDATION
FAA Airport Capacity Study
September 1974

Airport	Runways Designation	Weather	Sample Number	Mix (percent air carrier)	Percent Touch-and-Go	Flow Rate (operations per hour) Observed	Flow Rate (operations per hour) Calculated	Percent Difference
Chicago O'Hare International Airport (ORD)	27R/32R	VFR	1	89%	0%	76	84	+11%
			2	89	0	80	80	+ 0
			3	85	0	82	94	+15
			4	83	0	66	74	+12
			5	82	0	75	69	- 8
	14L/9L	IFR	1	100	0	70	73	+ 4
	27L/32R	VFR	1	72	0	77	89	+ 4
			2	85	0	70	79	+13
			3	92	0	68	66	- 3
			4	62	0	67	71	+ 6
			5	96	0	66	65	- 2
	14R/27L	IFR	1	97	0	77	87	+13
Dallas Love Field (DAL)	13R	VFR	1	71	0	59	63	+ 7
			2	71	0	54	60	+11
			3	92	0	53	60	+13
	13L/13R	IFR	1	74	0	76	74	- 3
Orange County (SNA)	19L	VFR	1	0	40	118	115	- 3
			2	0	53	137	130	- 5
	19R	VFR	1	6	22	106	97	- 8

Table III-4

GATE CAPACITY MODEL VALIDATION
FAA Airport Capacity Study
September 1974

Airport	Data Set Number	Date	Time Period	Number of Gates Observed	Flow Rate (operations per hour) Observed	Flow Rate (operations per hour) Calculated	Percent Difference
Chicago O'Hare	404	10/24/73	1000-1200	16	13	14	+ 7%
International	405	10/24/73	1335-1620	16	15	15	0
Airport (ORD)	406	10/25/73	1000-1230	16	14	14	0
	407	10/25/73	1415-1700	16	16	14	-13
	409	10/26/73	1445-1645	23	19	21	+11
	416	11/1/73	1145-1315	19	19	17	-11
	417	11/1/73	1435-1720	19	20	17	-15
	418	11/2/73	1045-1315	19	19	16	-15
	419	11/2/73	1500-1715	19	17	17	0
Dallas Love	508	11/9/73	1100-1215	18	16	18	+13
Field (DAL)	509	11/9/73	1448-1618	18	18	18	0
	512	11/13/73	1050-1205	19	18	19	+ 6
	513	11/13/73	1450-1620	16	19	16	-15
	514	11/14/73	1050-1150	19	20	19	- 5

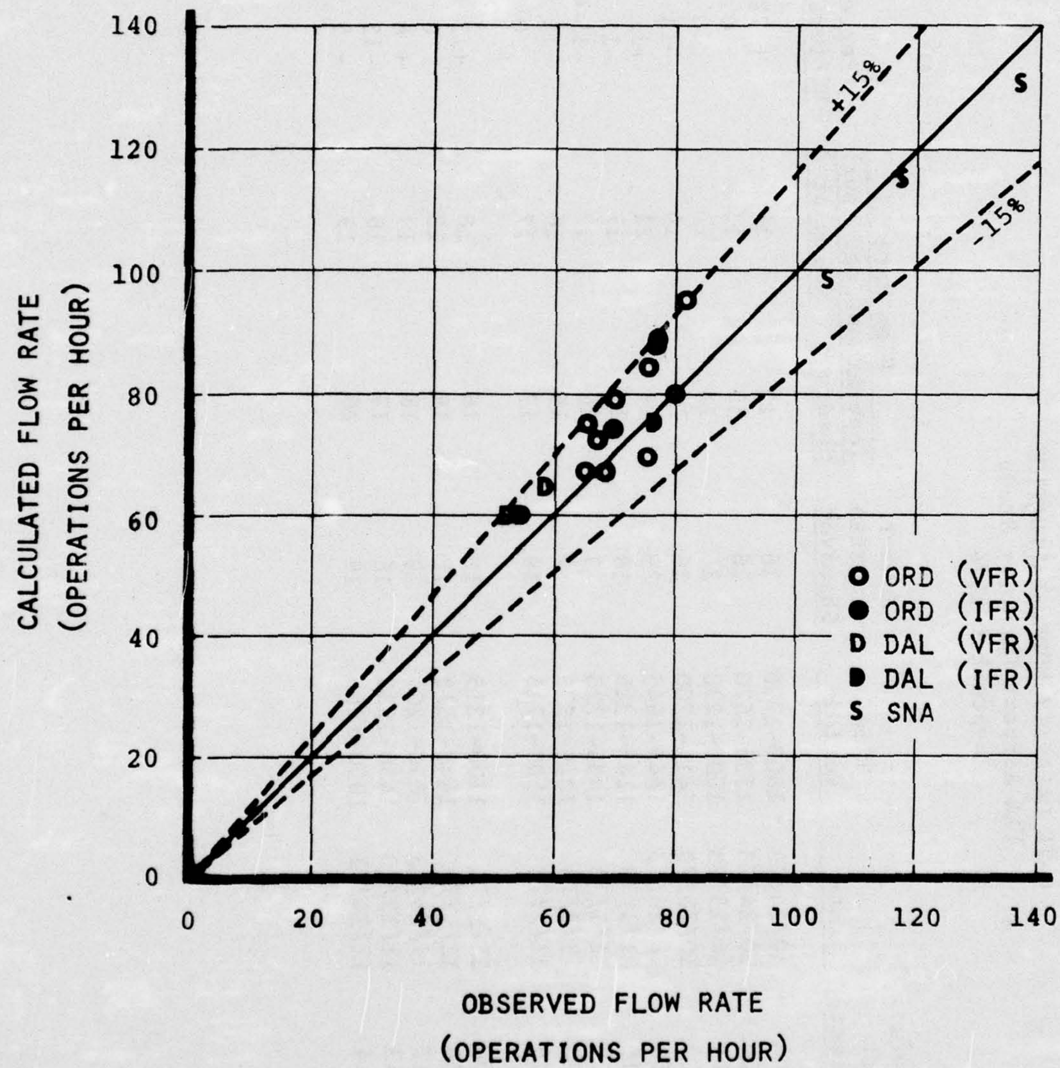


FIGURE III-28. RUNWAY CAPACITY MODELS VALIDATION

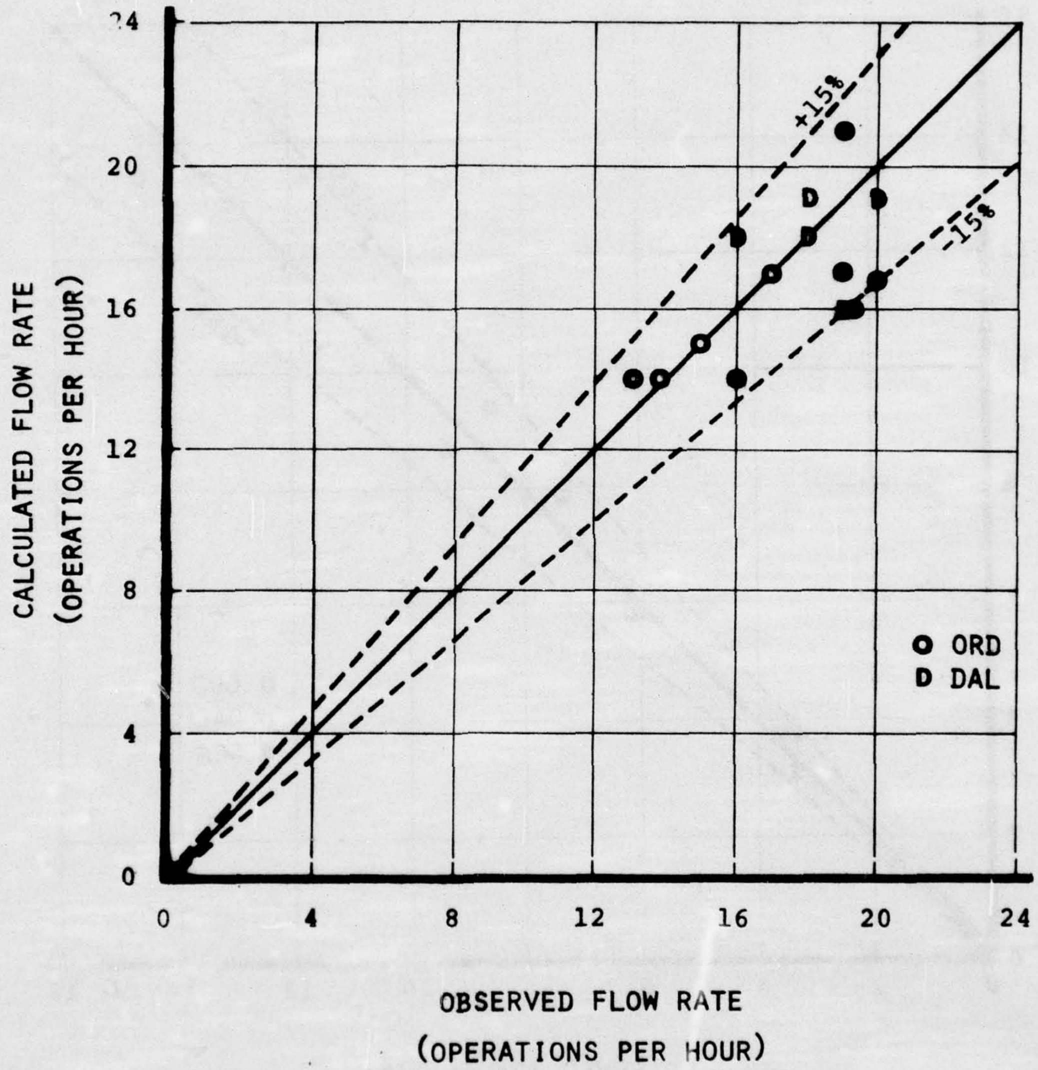


FIGURE III-29. GATE CAPACITY MODEL VALIDATION

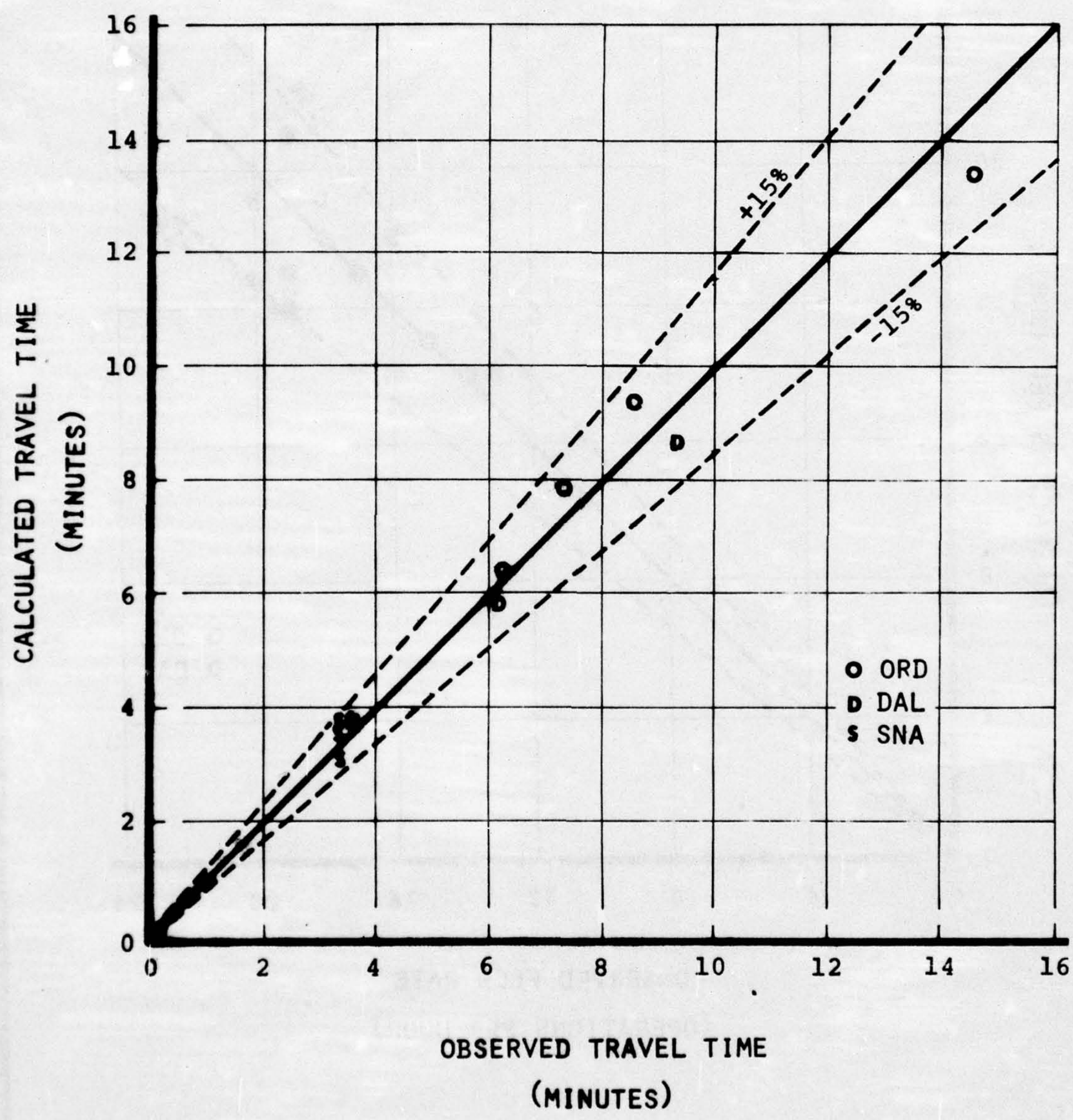


FIGURE III-30. DELAY MODEL VALIDATION

Table III-5

DELAY MODEL VALIDATION
FAA Airport Capacity Study
September 1974

Airport	Ground Travel Times (Minutes): Arrivals[a]			Departures[b]			All Operations			Arrival Air Travel Times[c]		
	Observed	Calculated	Percent Difference	Observed	Calculated	Percent Difference	Observed	Calculated	Percent Difference	Observed	Calculated	Percent Difference
Chicago O'Hare International Airport (ORD)	6.2	6.3	+1%	8.7	9.5	+ 9%	7.3	7.9	+8%	14.4	13.4	-7%
Dallas Love Field (DAL)	3.6	3.8	+5	9.3	8.7	- 6	6.1	5.9	-4	--[d]	--[d]	--[d]
Orange County Airport (SNA)	3.5	3.3	-5	3.5	4.0	+13	3.5	3.7	+5	--[d]	--[d]	--[d]

a. Arrival travel times were measured between the runway threshold and the gate.
b. Departure travel times were measured between the gate and the time clearance for takeoff was issued.
c. Arrival air travel times were measured between the coordination fix and the runway threshold.
d. Insufficient field data available for validation.

Chapter IV

HANDBOOK DEVELOPMENT

The Handbook evolved under the influence of diverse and often conflicting considerations during Phases I and II of the project. One of the most important and recurring considerations involved the trade-off between simplicity and accuracy of Handbook presentation. Professional judgments on the allocation of project resources were required for a Handbook that correlates with available data and meets the varied needs of the air transportation industry.

This chapter summarizes the principal technical studies undertaken within the context of these considerations and outlines the rationale leading to the format, content, and presentation concepts ultimately adopted for Handbook production.

The following pages are an overview of Handbook development decisions in Phase I. Following the overview, the coordination of the preliminary Handbook format is recapped, and the overall Handbook outline is set forth. Next, basic technical studies *affecting the overall Handbook* format are summarized, and the principal evaluations leading to the particular capacity and delay presentation concepts employed in the Handbook are described. Finally, this chapter discusses the process by which the various values of capacity and delay used in the preparation of Handbook charts were developed.

Phase I Efforts Related to Handbook Development

An overriding goal of the FAA and the project team was to develop procedures (handbooks, models, etc.) for application to a wide variety of airport planning and design problems. To account for the broad range of potential applications and the wide spectrum of resources available to potential handbook users, the Phase I efforts related to user needs and requirements were grouped together. These efforts, called "airport planning studies," dealt with:

- Uses of airfield capacity determination procedures and capacity handbooks.
- Concepts of capacity and delay.
- Preliminary format and scope of new capacity Handbook.

<u>Interviews with Handbook Users</u>. During the initial stage of Phase I, the following questions were emphasized:

1. What kind of information concerning airfield operations is desired for making decisions regarding planning and implementation of capital improvements and/or operational changes?

2. What are the practical uses of this information?

One of the first steps in the project was to conduct a series of interviews in the summer of 1972 with current handbook users: airport sponsors, airlines, the FAA, aviation associations, and airport consultants. The interview revealed:

- Many users cannot visualize existing runway capacity definitions in relation to actual events in the field; various ideas were given for the definition of capacity.

- There is a wide variety of both users of, and uses for, existing handbooks.

- Handbooks are not required for all airport planning and design problems; some airports are too complex for handbook solution.

- Adequate segregation of the types of problems to be analyzed is needed so that a handbook user need not read instructions that are not relevant to his problem.

- The Handbook (and models) should be responsive to a series of factors (weather, navigation aids, future ATC improvements, etc.) that affect airfield capacity.

- More emphasis is needed concerning general aviation airports.

- Most users want positive FAA planning and design criteria to evolve from this study.

In addition, even though there was no consensus on the meanings of capacity and delay, it became evident from the interviews and other parallel research that the most frequently required types of information are data on airfield capacity and delay to aircraft. Handbook users desire information on capacity and delay on each of the three components of the airfield (i.e., the runway, taxiway, and gate components), and on the airfield as a whole.

Users also indicated an occasional desire or need for other types of specific information on airfield performance such as queue lengths, locations of congestion points, and causes of congestion. Therefore, it was concluded that as much capacity and delay information as practicable should be presented in the new Handbook, and other performance measures should be provided from the basic capacity determination procedures (or models) that are developed.

Definitions of Capacity and Delay. Largely as a result of the user interviews, the definitions of hourly capacity, annual service volume, and delay set forth in Chapter I were adopted.

Preliminary Objectives for Handbook Format. Based on the user interviews, discussions with FAA technical personnel, and analyses by the project team, a number of objectives for development of the Handbook were derived. These objectives (which address both format and scope of the Handbook) are presented in the Phase I Report. They constituted the starting point for the preliminary formulation of the Handbook format in Phase I; and the continued evolution of the format throughout the refinement of the capacity and delay models and Handbook production in Phase II.

In accordance with these objectives, emphasis in the Handbook is placed on providing illustrative examples of computational procedures and self-explanatory charts and graphs. Examples were specifically selected to indicate how an airport planner and designer might extend the computational procedures to evaluate candidate improvements for the particular airfield configuration under consideration. In addition, the format of the Handbook is compatible with that of FAA Advisory Circulars.

Practical Uses of Handbook. In the development of the models and of the Handbook, special emphasis was given to dealing with the uses of airfield capacity and delay information in planning and design. As noted in the Phase I Report, the basic uses of capacity and delay information fall into three general classifications:

- Long-range planning including aviation systems planning and preliminary airport planning.
- Short-range improvement decisions and airport master planning.
- Other applications.

From the above, the airfield planning process may include several stages from preliminary assessment to detailed evaluation of airfield performance. The format of the Handbook, therefore, is structured to permit the user to choose a method of analysis best suited to his needs. The Handbook covers a wide range of practical conditions and airport configurations.

Preliminary Identification of Configurations. Preliminary analyses of airfield configurations for use in modeling studies and for incorporation in the Handbook are described in Appendix D of the Phase I Report. The final selection of configurations to be presented in the Handbook was deferred until Phase II, because the identification of those parameters that have the most significant effect on capacity and delay depended on model programming and sensitivity analyses. In addition, although it would be desirable for the Handbook to encompass the full range of configurations set forth in Appendix D of the Phase I Report, it was concluded that practical considerations (e.g., Handbook size) dictate that only a subset of all possible configurations be included.

Independence of Components. As part of the Phase I evaluation leading to the selection of the preferred types of capacity and delay models, an analysis was made of the independence of airfield component capacities where "independence" is defined as the lack of influence of one component on another component's capacity.

Practically, analytical models for determining capacity could be developed only for the individual airfield components. Therefore, the Phase I decision to use analytical models was made only after it was demonstrated that the capacity of the entire airfield system could be computed using the capacities of the individual components. This is the case for essentially all practical combinations of airfield components, as described in Appendix E of the Phase I Report. In the appendix, criteria was established for defining the approximate limitations of the independence of the capacities of the components.

As subsequently noted in this chapter, the independence of airfield component delays was also demonstrated during Phase II; for delays, "independence" is defined as a situation where delays to aircraft on one component do not influence delays on another component. Therefore, delays to aircraft on the entire airfield system are equal to the sum of the delays on the individual components.

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TECHNICAL REPORT ON AIRPORT CAPACITY AND DELAY STUDIES.(U)
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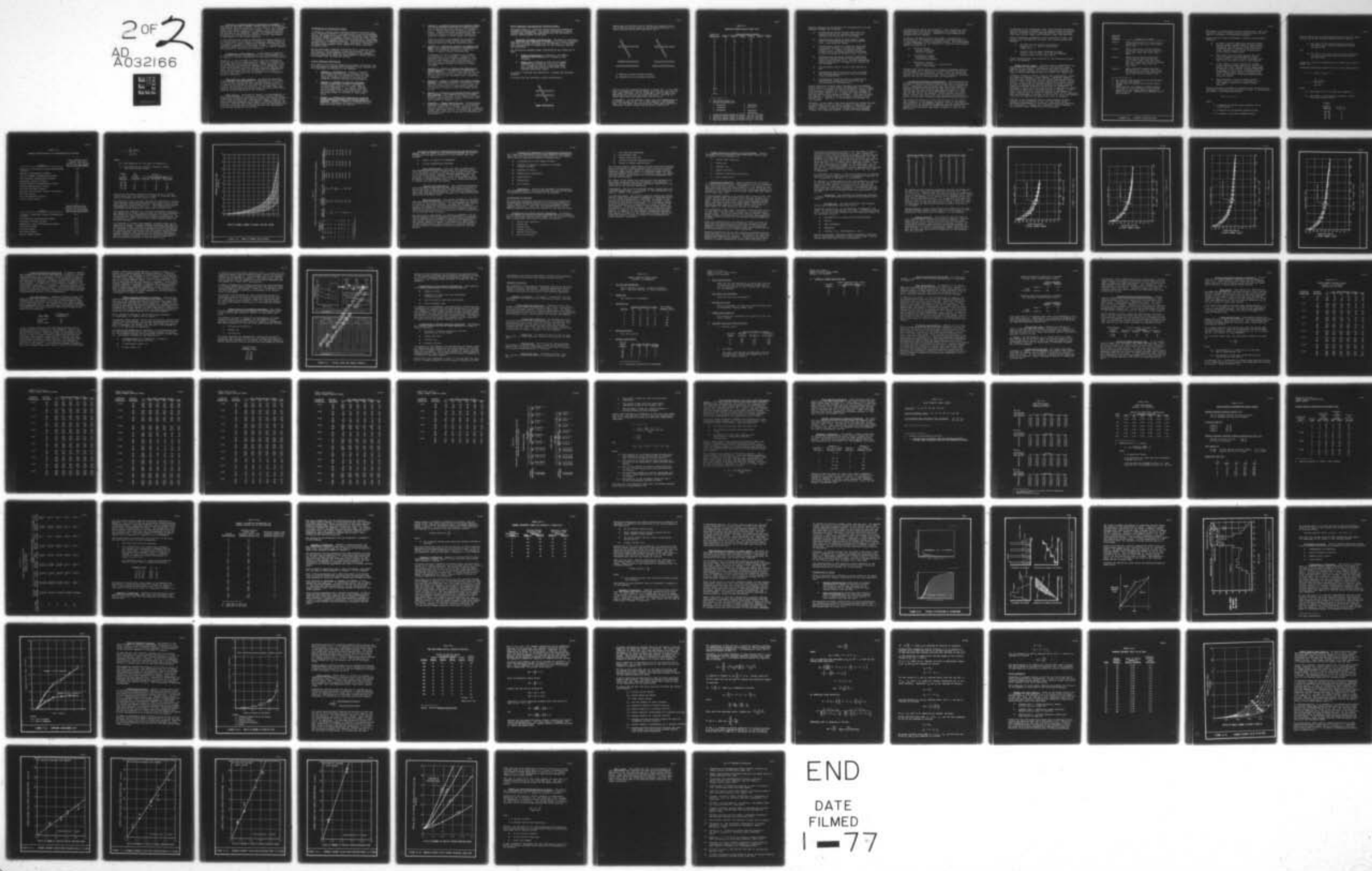

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Inclusion of Taxiway Capacity Information in Handbook. As described in the Phase I Report, taxiway capacity is generally much greater than the capacities of the runway or gate components, except when taxiways cross active runways. Thus, only taxiway capacity and delay information at taxiway-runway intersections are included in the Handbook. However, the Handbook contains procedures for determining the effect of taxiway improvements on the capacity of the runway component.

If the Handbook user wishes to determine if taxiway capacity is a limiting factor in an unusual circumstance, general models of the capacity of taxiway segments and taxiway intersections are contained in Appendix E of the Phase I Report. In addition, the simulation model described in Chapter II can be used to investigate details of special taxiway situations.

Conclusions on Gate Capacity. As described in Appendix E to the Phase I Report, all apron-gate area configurations can be reduced to one or a combination of their basic configurations.

Therefore, it was concluded in Phase I that the influence of apron and gate area configurations on capacity is minimal for all common apron-gate configurations. Except for airports that do not satisfy the criteria in Appendix E, to determine a balanced design between the gate and the runway and taxiway components, the airport planner and designer need be concerned primarily by the number and type of gates and the classes of aircraft using the gates--not the geometry (i.e., circulation lanes) of the apron.

Importance of a Gate Location. An important conclusion stems from both the independence of components and the results in the taxiway capacity and gate capacity studies in Phase I. In general, the location of the gates has little effect on capacities and delays on the airfield. On the other hand, the location of the gates can have an effect on travel times experienced by aircraft operating on the airfield.

Other Factors. As stated in Chapter 1 of the Handbook, it should be recognized that although airfield capacity and delay information is clearly important for justifying airfield improvements, other factors (e.g., environmental impact, financial implications) may ultimately be of equal, or possibly greater, importance. Although these other factors must be considered before final decisions are made on airport planning and improvements, they are not treated in this project.

Coordination of Preliminary Format

In Phase II, a draft report "Airfield Capacity and Delay Handbook, Preliminary Format" (referred herein to as the Preliminary Format) was prepared in April 1974[5] to coordinate study findings and obtain comment on Handbook format from FAA and other representatives of air transportation before committing a large number of resources to Handbook production. The Preliminary Format was prepared prior to completion of model validation, checkout of the delay model program, delay sensitivity tests, and model production runs.

Written and verbal comments received by FAA in connection with the review of the Preliminary Format were analyzed. To the extent possible, these comments are reflected in the Handbook. Primarily because of these and other comments, several key format concepts were reviewed and refined.

Overall Handbook Organization

As a result of the various Handbook development activities, the following general organizational framework of four chapters and five appendixes was adopted for the Handbook.

a. Chapter 1. Introduction. Chapter 1 outlines the purpose and scope of the Handbook; defines the airfield and its components; explains terms used; and suggests cautions in the use of the Handbook in airport planning and development.

b. Chapter 2. Analysis of Capacity and Delay. Chapter 2 describes a series of procedures for estimating capacity for a wide range of airfield components (i.e., runways, taxiways, and apron-gate areas). The chapter also contains procedures for determining hourly, daily, and annual delays to aircraft on these components.

c. Chapter 3. Computerized Technique to Determine Hourly Capacity of Runways and Annual Delay to Aircraft. Chapter 3 presents a computerized technique for determining the hourly capacity of runways and annual delay to aircraft.

d. Chapter 4. Airfield Evaluation by Computer Models. If a more detailed evaluation of capacity and delay is required than that possible from Chapters 2 or 3, the evaluation can be made by computer models. Chapter 4 briefly summarizes the scope of available simulation and analytical models and presents a summary of model inputs and outputs.

Capacity values in the Handbook were computed using analytical models whereas delays were computed using the computer simulation model.

e. Appendix 1 - Preliminary Analysis of Capacity and Delay. This appendix describes a simplified procedure for estimating capacity and delay for a number of typical runway configurations.

In general, the use of Chapters 2 or 3 rather than Appendix 1 is encouraged. Appendix 1 was prepared to provide a simple procedure for estimating runway capacity and annual delay to aircraft for use in preliminary planning when a very approximate estimate of capacity or delay is needed.

f. Appendix 2 - Effect of Ceiling and Visibility on Runway Capacity. A procedure to estimate the hourly capacity of a single runway and certain two parallel and intersecting runways when the visibility conditions are extremely poor is presented in Appendix 2.

g. Appendix 3 - Effect of Navigational Aids on Runway Capacity. Appendix 3 presents a procedure to estimate the hourly capacities of a single runway and certain two parallel and intersecting runways in IFR conditions without a radar environment and/or an ILS.

h. Appendix 4 - Evaluation of Runways Without Minimum Exit Taxiways. This appendix presents a simple procedure for determining runway capacity for small general aviation airports without the minimum taxiways assumed in Chapters 2 and 3.

i. Appendix 5 - Runway Restricted Use. The procedures presented in Chapter 2 are based on the assumption that all runways can be used by a majority of the aircraft using an airport. The capacities of parallel runways where some classes of aircraft are restricted from using a particular runway may be determined using Appendix 5.

Basic Technical Considerations Affecting Format

Throughout Phase II, technical studies supported Handbook development and production. The status and findings of these studies were reviewed and coordinated with FAA and others at several interim points of the work.

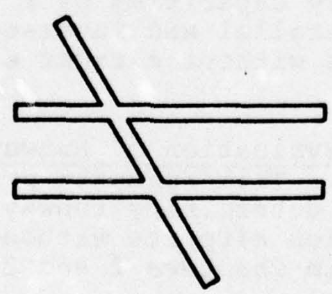
Selection of Runway Configurations. Two types of configuration selection were important in connection with runway capacity--selection of runway configurations for Appendix 1 of the Handbook, and selection of runway uses for the remaining chapters and appendixes.

The distinction between runway configuration and runway use is that:

- Runway configuration is defined as the number, location, and orientation of runways on the airfield.
- Runway use is defined in terms of the number, location, and orientation of active runways (i.e., runways in use at a particular time) and involves the directions and kinds of operations using each runway.

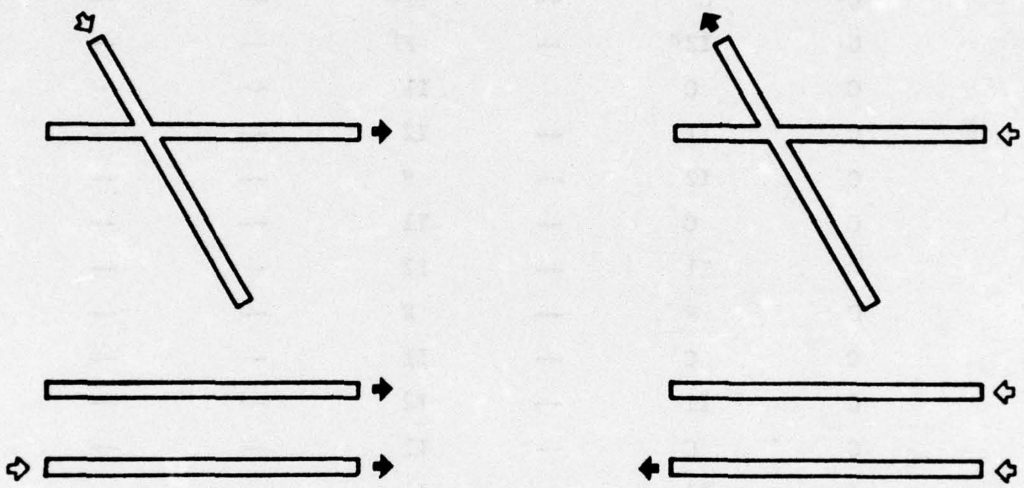
To further illustrate that definition, consider the following example:

An airport has the following runway configuration:



RUNWAY CONFIGURATION

Assume that the runways at this airport are normally used in four different ways as shown in the following diagrams (i.e., reflecting prevailing wind conditions, etc.):



ARRIVALS CAN OCCUR ON RUNWAY INDICATED.

DEPARTURES CAN OCCUR ON RUNWAY INDICATED.

Each of the four diagrams represents a runway use. In the Handbook, the symbol ⇨ is used to denote that arrivals may occur on the runway indicated, and the symbol ➡ is used to denote that departures may occur on the runway indicated. The lack of a symbol means that such operations will not occur.

In Appendix 1 of the Handbook, runway uses are predetermined as discussed on page IV-60. It is also assumed in the Handbook that, for the three- and four-parallel runway uses, centerline separations between runways are as shown in Table IV-1.

Table IV-1

SEPARATION BETWEEN PARALLEL RUNWAY USES

Runway Use Diagram No.[a]	Separation Between Runways[b] 1 and 2	2 and 3	3 and 4	1 and 3	1 and 4	2 and 4
13	C[c]	C	--	I1[d]	--	--
14	C	I2[e]	--	F[f]	--	--
15	C	C		I1	--	--
16	C	I1	--	I2	--	--
17	C	I2	--	F	--	--
18	C	C	--	I1	--	--
19	C	I1	--	I2	--	--
20	C	F	--	F	--	--
21	C	C	--	I1	--	--
22	C	I1	--	I2	--	--
23	C	C	--	I1	--	--
24	C	I1	--	I2	--	--
25	C	I2	--	F	--	--
26	C	C	--	I1	--	--
27	C	I1	--	I2	--	--
28	C	I2	--	F	--	--
29	C	C	--	I1	--	--
30	C	I1	--	I2	--	--
31	C	I2	--	F	--	--
32-36	C	I2	C	F	F	F
37	C	F	C	F	F	F
38-42	C	I2	C	F	F	F

a. From Handbook Figure 2-2.

b. Runways are numbered thus:

1.
2.
3.

1.
2.
3.
4.

c. Separation between runways is between 700 and 2,499 feet.

d. Separation between runways is between 2,500 and 3,499 feet.

e. Separation between runways is between 3,500 and 4,299 feet.

f. Separation between runways is between at least 4,300 feet.

Criteria employed in the selection of configurations for the Handbook included the following:

- Configurations should include those most frequently occurring at existing airports, particularly during periods of high demand.
- Configurations should include "logical expansions" to configurations at existing airports (e.g., a new parallel runway).
- Configurations should be limited to those with a reasonable balance of arrival and departure capacity (i.e., number of possible arrival streams should not normally differ from number of possible departure streams by more than one).
- Configurations should be limited to those with generally accepted operating strategies during high-activity periods (e.g., the two-intersecting runway configuration with two arrival streams was not included).
- Configurations should include those desired by FAA.
- Consideration should be given to cost of modeling and programming models for the various possible configurations.
- Consideration should be given to compatibility with Handbook presentation concepts for the various possible configurations.

During interviews, several users requested that the Handbook permit analysis of various stages of development from a simple airport (i.e., a minimum facility consisting of a single runway with turnaround taxiways, but without a parallel taxiway) to a basic airport layout (i.e., a runway with exit taxiways at each end and one exit taxiway in between). This type of analysis normally is limited to airports used by general aviation aircraft only. Appendix 4 of the Handbook was prepared for this purpose.

Similarly, it was evident that some consideration should be given to cases where the use of certain runways is restricted. For example, a restriction may be attributable to limited runway length or strength, insufficient lateral separation between a runway and a parallel taxiway, or aircraft noise abatement

or preferential runway use procedures. Most frequently, such restrictions in the use of a runway apply to larger, heavier aircraft using the airport. Appendix 5 of the Handbook was prepared for this purpose.

To satisfy the above criteria and needs, a comprehensive investigation of all possible configurations was undertaken prior to the preparation of the Preliminary Format. The investigation included assessment of the frequency of occurrence and relative effect on capacity of:

- Parallel Runways
  - Lateral separation
  - Threshold stagger
- Intersecting Runways
  - Intersection angle
  - Intersection distance
- Nonparallel Runways
  - Lateral separation at closest point
  - Angle of divergence

Through these investigations and various coordination sessions, a preliminary set of preferred configurations was identified and included in the Preliminary Format. Since the review and comments on the Preliminary Format, several revisions have been made to the list of configurations in the Handbook.

Selection of Aircraft Classification. Before Handbook production, appropriate classifications of aircraft were selected. In Phase I, aircraft initially were grouped into 12 generalized types. Subsequent analyses showed that the minimum number of aircraft classifications should be used consistent with model sensitivity, but that every attempt should be made to reduce the aircraft classes to a more manageable number (i.e., less than 12) for use in the Handbook. Since the data collection effort, further experience with wake turbulence caused FAA to modify the ATC rules influencing separation between aircraft.[10]

The revised FAA separation rules had no effect on the conceptual framework of the capacity and delay models to be used in the production of the Handbook; however, the new rules permitted a reduction in the number of classes required to account for special rules previously applicable to heavy tri-jets (L-1011 and DC-10).

In addition to air separation rules, other possible parameters were investigated in connection with possible aircraft classifications, including aircraft approach speeds, runway occupancy time, exit taxiway usage, gate occupancy times, and gate size.

After considerable discussion of the trade-offs of cost, complexity, and acceptability to users, two classifications were adopted:

- Aircraft mix for runways and taxiways--Classes A, B, C, and D as defined in Figure IV-1.
- Aircraft mix for gates--widebody aircraft (B-747, DC-10, L-1011, etc.) and non-widebody aircraft (DC-8, B-707, DC-9, etc.)

These classifications were presented in the Preliminary Format and in the Handbook.

Annual Service Volume. Previous capacity handbooks[8,9] presented means to calculate a measure of the practical annual capacity of the runways. This measure was used (primarily by FAA) to indicate service levels at an airport and whether proposed airfield improvements might be eligible for federal aid.

Different concepts of annual capacity were investigated, revealing technical problems in each concept. Saturation capacity concepts, while consistent with the hourly capacity definition, give very high values that are not particularly useful planning guides. Level of service concepts, while giving values similar in order of magnitude to previous measures of annual capacity, depend on arbitrary subjective definitions of "acceptable" or "tolerable" levels of service and can give a wide range of values depending on the pattern (of fluctuations) of demand. In addition, to be useful for preliminary planning, the measure of annual capacity must be simple to compute, which is not compatible with the requirement to account for the hourly, daily, and seasonal variations in capacity and demand that occur at airports.

Although it was recognized that no single measure of annual capacity could be produced to meet all user needs (while satisfying requirements of technical consistency and simplicity of calculation), a concept for a measure of annual capacity was selected, while recognizing its limitations.

Aircraft Classification	Types of Aircraft[a]
Class A	Small single-engine aircraft weighing 12,500 lb[b] or less (e.g., PA18, PA23, C180, C207)
Class B	Small twin-engine aircraft weighing 12,500 lb[b] or less and Lear jets (e.g., PA31, BE55, BE80, B99, C310, C402, LR25)
Class C	Large aircraft weighing more than 12,500 lb[b] and up to 300,000 lb[b] (e.g., CV34; CV58; CV88; CV99; DC4; DC6; DC7; L188; L49; DC8-10, 20 series; DC9; B737; B727; B720; B707-120; BA11; S210)
Class D	Heavy aircraft[c] weighing more than 300,000 lb (e.g., L1011; DC8-30, 40, 50, 60 series; DC10; B707-300 series; B747; VC10; A300; Concorde; IL62)

a. For aircraft type designators, see FAA Handbook No. 7340.1E with changes.
b. Weights refer to maximum certificated takeoff weight.
c. Heavy aircraft are capable of takeoff weights of 300,000 lb or more whether or not they are operating at this weight during a particular phase of flight. (Reference FAA Handbook 7110.65 with changes.)

FIGURE IV-1. AIRCRAFT CLASSIFICATION

The measure is called annual service volume (ASV), and is defined as a level of annual aircraft operations that may be used as a reference in preliminary planning.

Annual service volume is designed to reflect the following criteria:

- As annual aircraft operations approach annual service volume, average delay to each aircraft throughout the year may increase rapidly with relatively small increases in aircraft operations, thereby causing levels of service on the airfield to deteriorate.

- When annual aircraft operations on the airfield are equal to annual service volume, average delay to each aircraft throughout the year is on the order of one to four minutes.

- If the number of annual operations exceeds annual service volume, moderate or severe congestion may occur, similar to that experienced at several of the airports surveyed during the development of this report (including Chicago O'Hare International Airport, LaGuardia Airport, and William B. Hartsfield Atlanta International Airport).

- Where feasible, values of annual service volume should be similar to measures of annual capacity reported in previous handbooks.[8,9]

Various alternative methods of calculating ASV values were investigated, including those developed in Phase I. Each concept was based on the following equation.

$$ASV = C \times D \times H$$

where

C = a measure of average hourly capacity (on an annual basis)

D = a measure of the seasonal demand profile

H = a measure of the daily demand profile

Initial evaluation of resulting delay levels and data availability led to the following definitions of D and H.

D = the ratio of the annual aircraft operations to average daily aircraft operations during the peak month

and

H = the ratio of average daily aircraft operations to average peak hour aircraft operations of the peak month

Values of D and H for representative airports are given in Table IV-2.

Three main alternative definitions of C were investigated:

1. $C = (C_{VFR} + C_{IFR}) \div 2$

2. $$C = \frac{\sum_{i=1}^{n} C_i W_i P_i}{\sum_{i=1}^{n} W_i P_i}$$

where

P_i = the proportion of the year with capacity C_i

W_i = the weight to be applied to capacity, chosen from the following table.

Percent of Maximum Capacity	Weight W_i
90-100	1
81- 90	2
66- 80	4
51- 65	8
40- 50	12

Table IV-2

DEMAND CHARACTERISTICS FOR REPRESENTATIVE AIRPORTS

Airport	D Ratio Between Annual Traffic and Daily Traffic on the Average Day of the Peak Month
William B. Hartsfield Atlanta International Airport	349
Honolulu International Airport	343
John F. Kennedy International Airport	340
San Francisco International Airport	339
Washington National Airport	338
Denver Stapleton International Airport	334
Oakland International Airport	321
San Jose Municipal Airport	317
McCarran International Airport (Las Vegas)	312
Van Nuys Airport	306
Reno International Airport	280
Fulton County Airport	279

Airport	H Ratio Between Daily Traffic and Peak Hour Traffic on the Average Day of the Peak Month
William B. Hartsfield Atlanta International Airport	13.7
San Francisco International Airport	13.5
Washington National Airport	12.3
Lambert-St. Louis International Airport	11.9
Dallas Love Field	11.6
Van Nuys Airport	8.6
Opa Locka Airport	8.2
Fulton County Airport	7.1

3. $$C = \frac{\sum_{i=1}^{n} C_i W_i P_i}{\sum_{i=1}^{n} W_i P_i}$$

where

P_i = the proportion of the year with capacity C_i

W_i = the weight to be applied to capacity, chosen from the following table.

Percent of Maximum Capacity	Mix Index in VFR	Weight W_i		
		Mix Index in IFR		
	0 to 180	0 to 20	21 to 50	51 to 180
90-100	1	1	1	1
81- 90	5	1	3	5
66- 80	15	2	8	15
51- 65	20	3	12	20
0- 50	25	4	16	25

For each of the three alternative definitions of C, ASV and annual delays were calculated for a number of different combinations of runway uses and aircraft mixes.

The results of these analyses indicate that definition 3 (above) gives the best correlation between average annual delay and the ratio between annual demand and ASV. The range of delay values encountered is shown in Figure IV-2. Other definitions of C give delay values outside the range shown in Figure IV-2.

ASV values were computed for a variety of operating conditions and compared with values computed using the previous technique.[8,9] The results of these computations, presented in Table IV-3, indicate that ASV values have the same order of magnitude as, and are generally slightly higher than, values computed using the previous technique.

For analyses of airfield improvements, aircraft delays can be important at levels of annual aircraft operations less than annual service volume. Therefore, delays to aircraft should also be considered in planning and evaluating airfield improvements at levels of annual operations less than annual service volume. In some instances, when annual service demand is expected to approach one-half of annual service volume within the planning horizon, nominal construction costs of airfield improvements may be balanced by savings in aircraft delay costs.

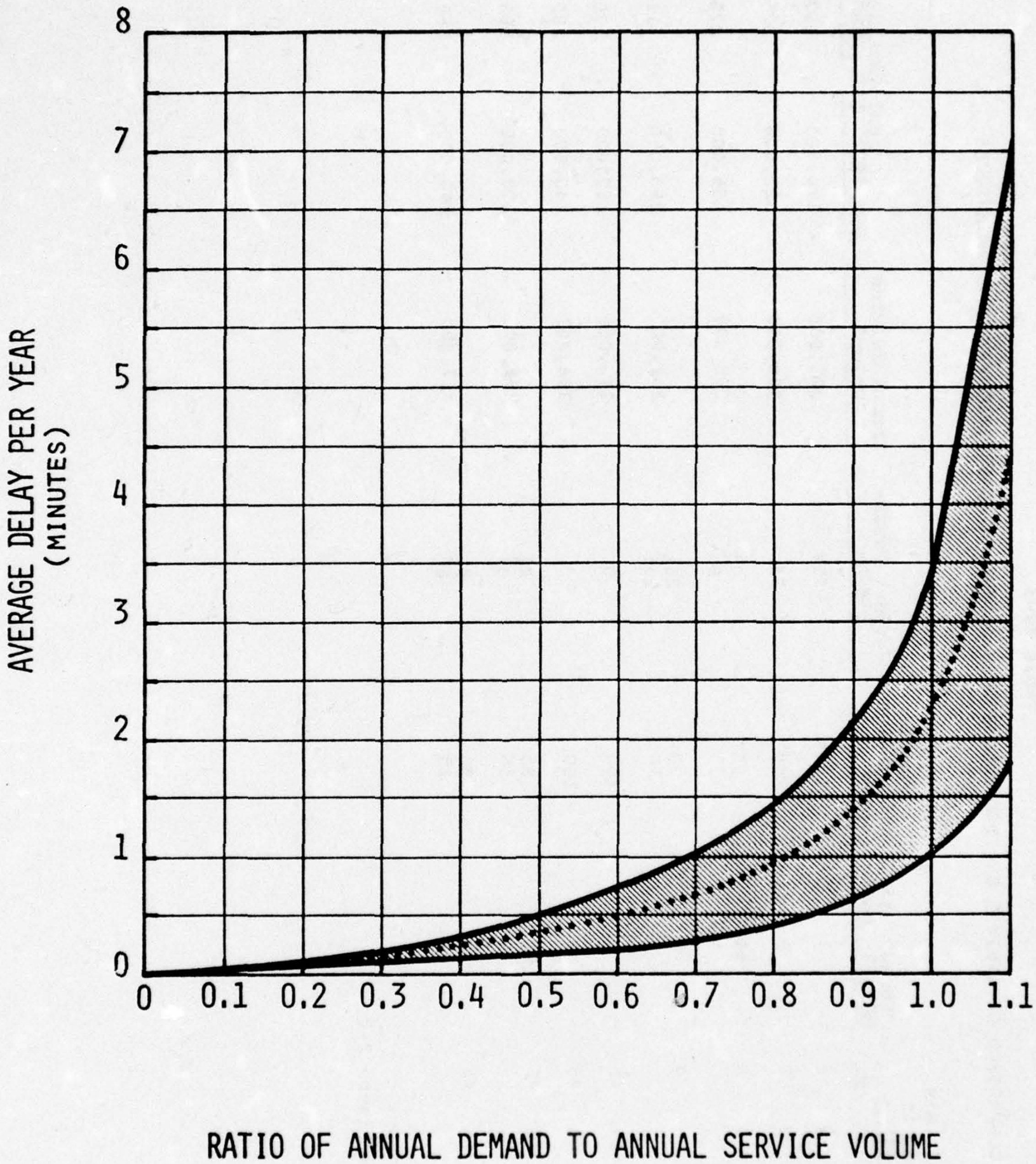


FIGURE IV-2. RANGE OF ANNUAL DELAY VALUES

Table IV-3

COMPARISON OF ARRIVAL SERVICE VOLUME WITH ANNUAL CAPACITY FROM PREVIOUS TECHNIQUES

Case No.	Aircraft Mix (percent in class) A	B	C	D	Runway Use Diagram No.[a]	Annual Utilization (percent)	Percent Touch-and-Go	Annual Service Volume	Annual Capacity From Ref. 8	Annual Capacity From Ref. 9
1	90	10	0	0	1	100%	25%	283,000	170,000	182,000
2	90	10	0	0	9	100	25	380,000	320,000	325,000
3	90	10	0	0	44 1	65 35	0 0	258,000	155,000	220,000
4	90	10	0	0	9 1	90 10	25 25	359,000	250,000	311,000
5	0	10	45	45	1	100	0	243,000	180,000	170,000
6	0	10	45	45	9	100	0	364,000	340,000	280,000
7	0	10	45	45	44 1	65 35	0 0	251,000	190,000	183,000
8	0	10	45	45	9 1	90 10	0 0	317,000	240,000	269,000

a. From Handbook Figure 2-2.

Alternative Methods of Presenting Capacity and Delay Information. Early in Phase II, two alternative methods for presenting capacity and delay information in the Handbook were considered:

- Charts (or tables or nomographs)
- On-line computerized technique

Chart Presentation. With this type of presentation, the Handbook would contain methodologies for computing capacities and delays in graph or tabular form similar to that found in the existing airport (runway) capacity handbooks and along the lines of the format described in the Phase I Report. Essentially, the methodology would consist of utilizing a series of charts or tables combined with, at most, simple calculations to compute the capacities and delays.

Computerized Presentation. The computerized presentation would rely on computers for the computation of desired capacity and delay values and would contain instructions on the use of the computer system adopted. Variations in computer systems range from remote teletype terminals to a more conventional batch mode processing system.

Both Alternatives. With either alternative, the Handbook user would be required to provide inputs which are normally available to the airport planner. If the Handbook user desires to vary more inputs than normally available for purposes of making a more detailed, sophisticated evaluation of specific improvements, changes in air traffic control procedures, and the like, he would be required to stipulate all inputs corresponding to this desired level of detail.

The provision of such detail in a capacity handbook is not desirable because it would unnecessarily complicate the presentation of methodologies intended for general planning and design. Such further detail would require description of additional, and perhaps unfamiliar inputs. Such detail and sophistication is more appropriate for the description of the basic capacity and delay models and computer programs presented in the User Manual.

Criteria for Comparison of Presentation Alternatives. As a result of discussions with various members of the project team, the following criteria were established for the comparison of the two alternative methods of presentation:

- Acceptability to full range of users
- Coverage of option in relation to intended context of usage
- Accuracy of result
- Simplicity or complexity
- Accessibility
- Reliability
- Cost impacts

Conclusions. Based on the subsequent investigations and recommendations, it was *determined* by FAA that both methods of presentation should be included in the Handbook.

Presentation of Capacity

The following paragraphs describe the selection of appropriate Handbook chart presentation methods for the determination of hourly capacity of the different airfield components--runways, taxiways, and gates. (Note that the Handbook should not be used to calculate capacities for periods of less than one hour.)

Presentation of Runway Capacity Information. An analysis of the results of sensitivity tests performed during the development of the runway capacity model showed that 11 principal factors have a potentially significant influence on capacity.

1. Ceiling and visibility
2. Runway Use
3. Aircraft mix
4. Percent arrivals
5. Percent touch-and-go
6. Exit configuration

7. ATC rules and procedures
8. Navigational aids
9. Runway restricted use
10. Aircraft operating characteristics
11. Length of common approach path

The last two factors listed above--aircraft operating characteristics and length of common approach path--do not vary significantly in terms of their impact on capacity at most airports. Therefore, these factors were not considered further for purposes of Handbook presentation. At airports today, the seventh principal factor listed above--ATC rules and procedures--does not vary significantly.

The impact of the eighth and ninth factors--navigational aids and runway restricted use--was determined to be important under certain special conditions; therefore, these factors are addressed in the Handbook appendixes.

Consequently, the first six principal factors listed above are discussed subsequently in the context of the presentation concepts in Chapter 2 and Appendix 1.

As noted previously, the airfield planning process may include several stages from preliminary assessment to detailed evaluation of airfield performance. Therefore, the format of the Handbook is structured to permit the user to choose a method of analysis best suited to his needs. In this regard, runway capacity information is presented at two levels of detail in the Handbook. In Chapters 2 and 3, the user must obtain data concerning the first six principal factors influencing runway capacity in order to use the capacity determining procedure. However, in Appendix 1 of the Handbook assumptions were made with respect to several of the first six principal factors influencing capacity in order to simplify the presentation of runway capacity information.

Runway Capacity in Chapter 2 of the Handbook. The six principal factors influencing the presentation concept used in Chapter 2 of the Handbook are:

1. Ceiling and visibility
2. Runway use
3. Aircraft mix
4. Percent arrivals
5. Percent touch-and-go operations
6. Exit configuration

Ceiling and Visibility. Analysis showed that the effect of ceiling and visibility on runway capacity could be considered as a set of discrete changes. Furthermore, as a result of the user interviews conducted during Phase I, it was determined that two major classifications of ceiling and visibility should be retained if at all possible--visual flight rules (VFR) and instrument flight rules (IFR).

In the airspace adjacent to an airport with a control zone, VFR (visual flight rules) conditions occur when the ceiling is at least 1,000 feet and the visibility is at least three statute miles. During VFR conditions, pilots space themselves according to what they consider safe except where aircraft are sequenced by radar such as in Terminal Control Area (TCA) or where Stage III radar sequencing service is provided.

IFR (instrument flight rules) conditions occur when the ceiling is less than 1,000 feet and/or visibility is less than three statute miles. During IFR conditions, the air traffic control system assumes the responsibility for providing safe separation between aircraft and specifies the minimum spacing between all aircraft.

These two classifications are desired by airport planners because they are associated with significant changes in runway capacity, and because meteorological data are collected and compiled in categories that allow for the simple determination of the occurrence of each of these conditions.

Although appropriate for the vast majority of Handbook applications, the use of VFR and IFR is a simplification of real world operating procedures and practices. In reality, the effect of ceiling and visibility on capacity is complex and varies from airport to airport depending on actual site conditions, etc.

In planning high-activity airports, the occurrence of certain visibility and ceiling conditions (i.e., poor visibility/ ceiling or "PVC") may be significant enough to warrant further analysis of runway capacity during IFR conditions. For the Handbook, PVC conditions are defined as occurring when ceiling is below about 500 feet and/or the visibility is less than about one mile (i.e., slightly above operating minima). Therefore, PVC conditions are a subset of IFR conditions. One of the important differences between PVC and IFR conditions is that in PVC, a two-mile departure-arrival separation is required, whereas in some IFR conditions, visual relief from this rule is permitted.

In conclusion, for Chapter 2, VFR and IFR were used as measures relating to ceiling and visibility; information on capacity in PVC is presented in Appendix 2 of the Handbook.

For Chapter 2, runway capacities were calculated for a ceiling of 800 feet and a visibility of 2.5 miles for IFR, and for a ceiling of 3,500 feet and a visibility of 5 miles for VFR. These values for ceiling and visibility are representative of conditions that occur most frequently in IFR and VFR and also are associated with the maximum capacities anticipated in IFR and VFR.

Runway Use. The selection of runway uses presented in Chapter 2 of the Handbook was described previously in this chapter.

Aircraft Mix. As noted previously, four aircraft classes were identified (see Figure IV-1).

To portray aircraft mix, it was necessary to determine a mix index. To select an appropriate mix index, a preliminary analysis of various mix index possibilities was made with respect to the following criteria:

- Applicability to existing and projected mixes
- Accuracy
- User confidence
- Complexity
- Coverage (i.e., configurations, etc.)

During the analysis, prototype handbook production runs were made to investigate further mix index possibilities. The following mixes were used in this investigation:

Percent Aircraft in Class				Percent Aircraft in Class			
A	B	C	D	A	B	C	D
100	0	0	0	25	25	40	10
95	5	0	0	25	25	35	15
85	15	0	0	20	20	50	10
80	20	0	0	25	25	30	20
65	25	10	0	20	20	40	20
60	30	10	0	15	15	55	15
50	35	15	0	20	20	35	25
40	40	20	0	10	20	45	25
50	35	10	5	10	10	60	20
35	35	30	0	0	10	70	20
40	35	20	5	0	20	55	25
35	35	25	5	0	10	60	30
30	30	35	5	0	10	50	40
30	30	30	10	0	10	45	45
30	30	25	15				

The results of the prototype production runs for the single runway use in VFR conditions are depicted in Figures IV-3, IV-4, IV-5, and IV-6. These figures show the variation of runway capacity as a function of the four mix indexes considered at an interim point in the analysis, i.e., Percent (C+D), Percent (C+2D), Percent (C+3D), and Percent (C+4D). It is apparent from these figures, as from similar analyses of the other configurations, that Percent (C+3D) is the most desirable mix index. This mix index is applicable for representative mixes currently occurring at U.S. airports.

Because capacity varies continouously with changes in mix index, the relationship between runway capacity and mix index is presented as a continuous curve in Chapter 2 of the Handbook.

Percent Arrivals. An analysis of data for several U.S. airports showed that percent arrivals generally range between 35% and 65% at periods of significant traffic volume. Since capacity varies continuously with percent arrivals, the relationship between runway capacity and percent arrivals is presented so as to permit interpolation between different percent arrivals. To aid in interpolation, three levels of percent arrivals were selected for presentation in the Handbook-- 40%, 50%, and 60%.

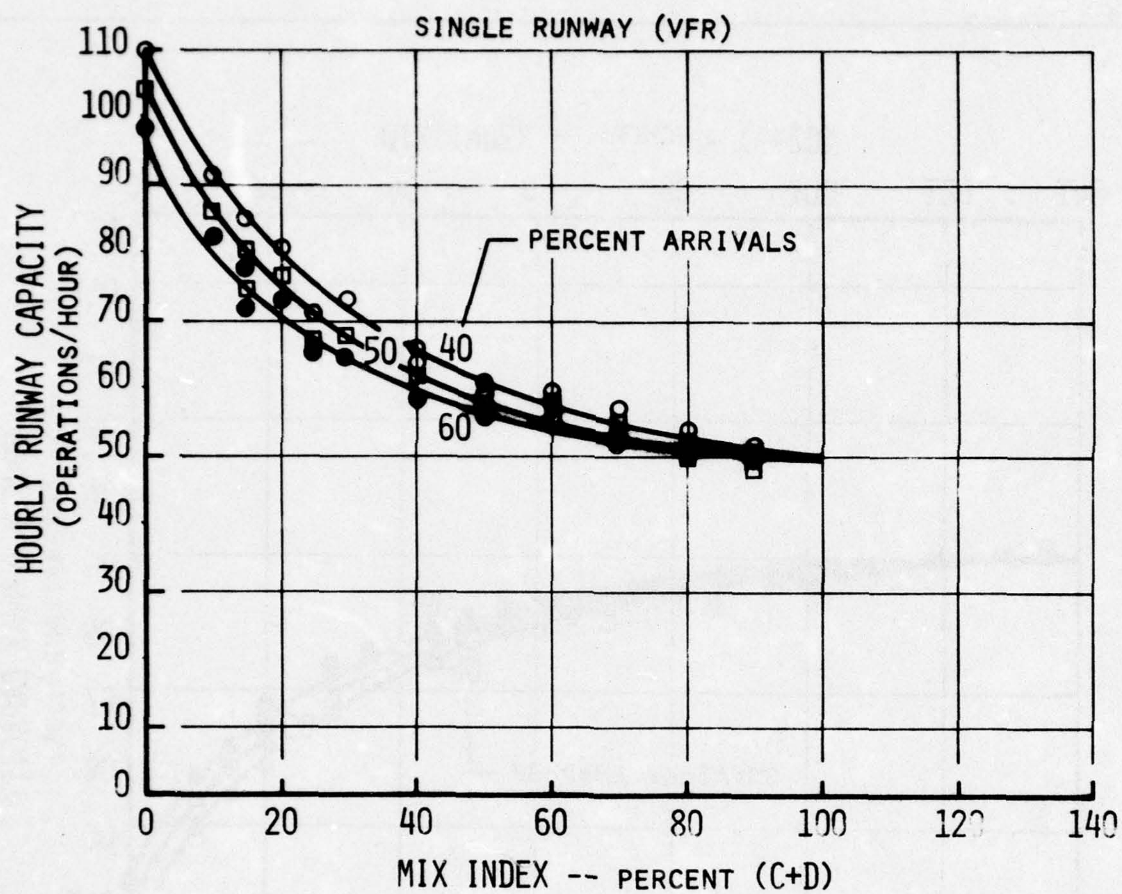


FIGURE IV-3. MIX INDEX (C+D)

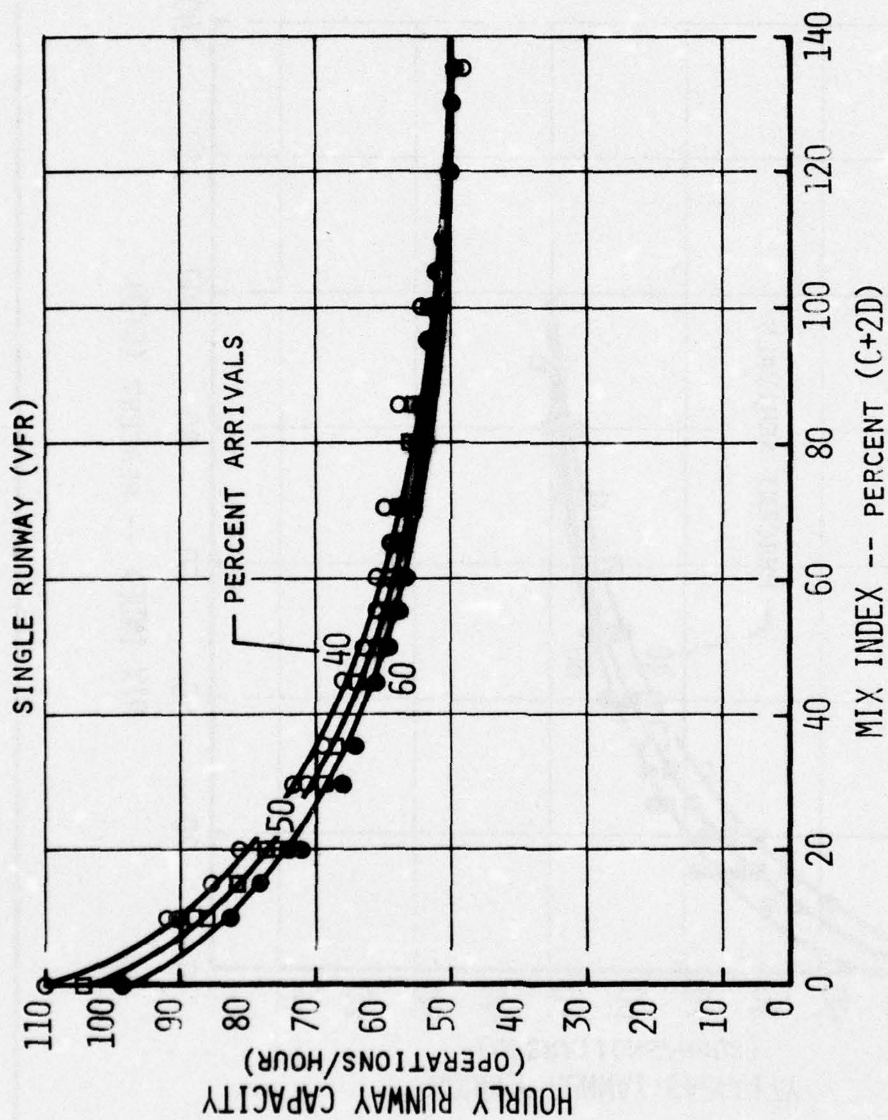


FIGURE IV-4. MIX INDEX (C+2D)

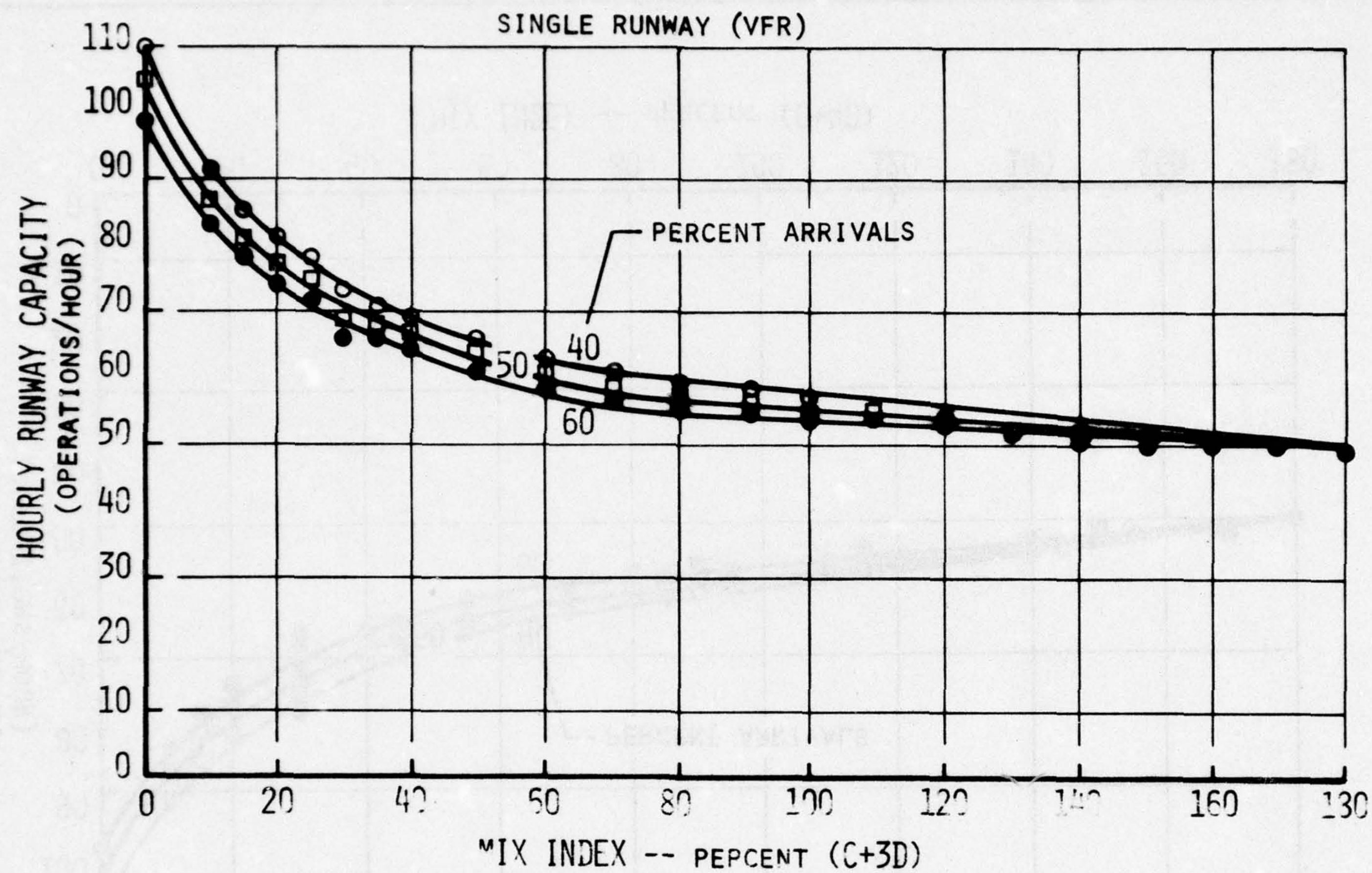


FIGURE IV-[illegible]. MIX INDEX (C+3D)

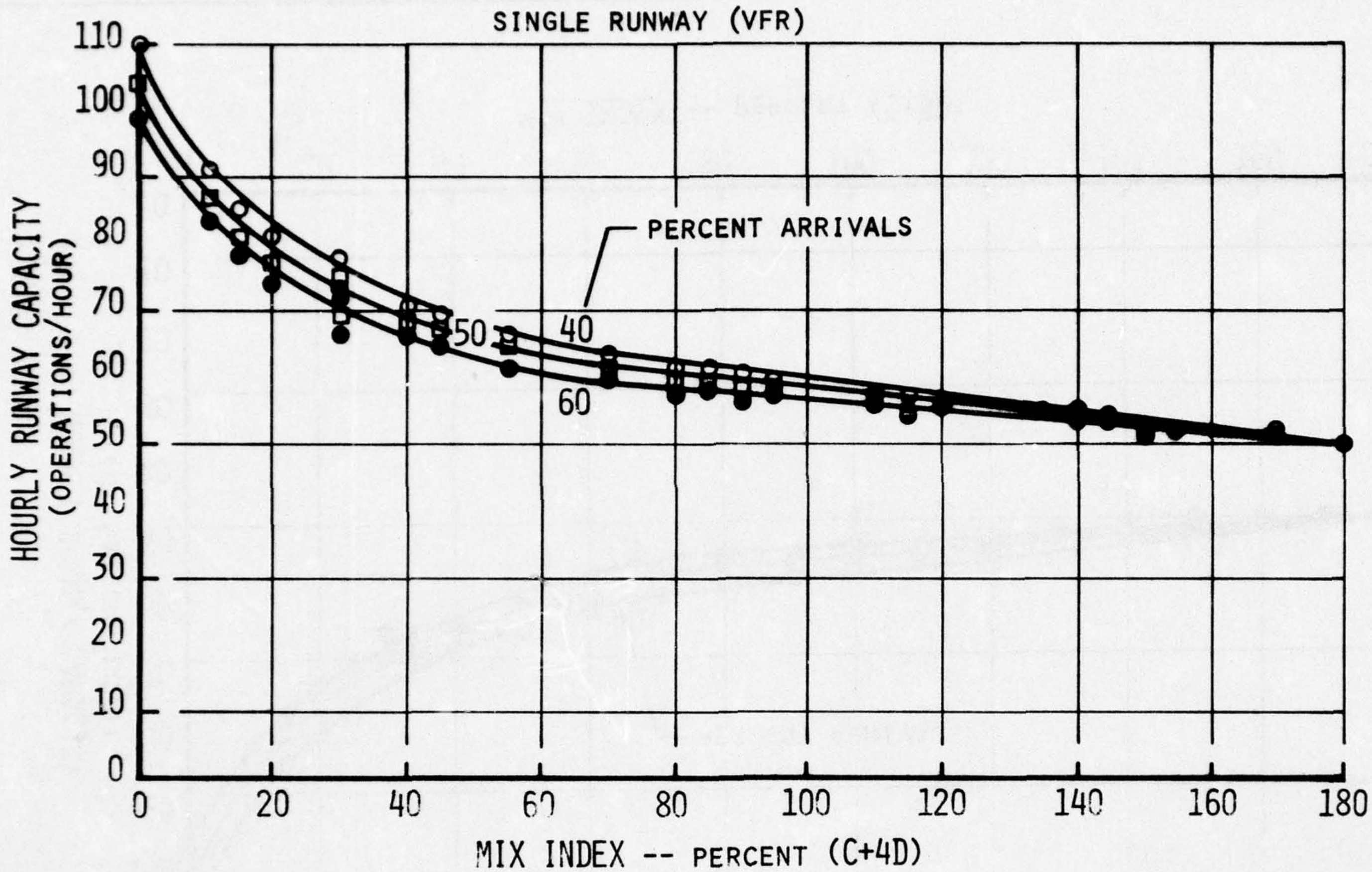


FIGURE IV-6. MIX INDEX (C+4D)

Percent Touch-and-Go Operations. In general, significant numbers of touch-and-go operations do not occur at airports used predominantly by air carrier aircraft; therefore, the influence of touch-and-go operations in the planning of such airports may not be important. However, touch-and-go operations are important at airports used almost entirely by general aviation aircraft. In Chapter 2 of the Handbook, a maximum of 50% touch-and-go operations is considered. Although capacity varies continuously with changes in percent touch-and-go operations, a sensitivity analysis revealed that it would be possible to group ranges of percent touch-and-go operations without significantly diminishing the accuracy of the presentation.

Exit Configuration. Analyses of arrival runway occupancy time and exit utilization data collected during Phase I indicated that with current pilot and aircraft operating practices and characteristics, the influence of exit type on capacity is relatively minor. For example, arrival runway occupancy times associated with various exit types are shown in the following tabulation for Class C aircraft using exits located 6,000 feet from the threshold:

Exit Type	Occupancy Time (seconds)
High-Speed	54
Angle	56
Right Angle	56

It was therefore concluded that exit type would not be considered further for Chapter 2 of the Handbook. However, it was concluded that the effect of number and location of exits should be considered. Sensitivity tests on the number and location of exits on runway capacity showed that for each aircraft mix, there exists a range of exit locations that can significantly influence runway capacity. Outside this range, the presence or absence of exits has much less influence on capacity as long as there is at least one exit taxiway at each end of the runway. It was therefore assumed in Chapter 2 that, at a minimum, such exits exist at each end of each runway.

However, there may be occasions when a capacity analysis is required for a runway without the minimum taxiways. Typically, such an analysis is important in connection with the staged development of a simple airport (i.e., a minimum facility consisting of a single runway without a turnaround or a parallel taxiway) into a basic airport layout (i.e., a runway with exit taxiways at each end and one exit taxiway in between). This type of analysis normally is limited to airports used solely by general aviation aircraft. Therefore, Appendix 4 of the Handbook presents a simple procedure for determining runway capacity for such airports without the minimum taxiways. The procedure permits the determination of runway capacity for various stages of improvement of a simple airport.

Runway Capacity Presentation Concepts. From the discussion of the six principal factors listed above, it is evident that two of the factors--ceiling and visibility and runway use--are associated with specific fixed assumptions. Therefore, the remaining four principal factors--aircraft mix, percent arrivals, percent touch-and-go, and exit configuration--should ideally be presented on a single exhibit for each combination of ceiling and visibility and runway use to portray the interrelationships between the six principal factors in a convenient manner.

Three alternative methods of presentation were evaluated: (1) nomographs, (2) charts, and (3) tables.

A nomograph system similar to that used in previous capacity handbooks[6,7] was investigated. The project team determined that such nomographs, while not difficult for the experienced and familiar user to interpret, may detract from the use of the Handbook because of an impression of complexity.

To minimize the impression of complexity, it was determined that the chart presentation should use a simple equation to account for the different factors that significantly affect runway capacity. The factors included in the equation are:

- A capacity base (C*) computed for a specific mix index and percent arrivals
- A touch-and-go factor (T)
- An exit factor (E)

If there are no touch-and-go operations and if a "good" exit configuration exists, then the capacity base is equal to the hourly capacity of the runway(s). Stated another way, in the computation of hourly capacity of runway(s), the touch-and-go and exit factors account for the presence of touch-and-go operations and the absence of a "good" exit configuration.

A tabular presentation of runway capacities was also formulated on a single exhibit showing capacity values for specified fixed values assigned to each factor. Figure IV-7 illustrates a typical chart and tabular presentation considered at an interim point in the study.

The project team evaluated the three alternative methods of presenting concepts and chose the chart-type method for Chapter 2 because it (1) illustrates graphically the sensitivity of runway capacity with respect to the six principal factors, and (2) allows graphic interpolation of mix index and percent arrivals.

Runway Capacity in Handbook Appendixes. The concept for the presentation of runway capacity in the Handbook appendixes parallels the concept in Chapter 2 to the extent possible.

For example, in order to simplify the presentation of runway capacity information in Appendix 1 of the Handbook while paralleling the presentation concept of Chapter 2, assumptions were made concerning all but the first three principal factors:

1. Ceiling and visibility

2. Runway use

3. Aircraft mix

To further simplify the presentation, ceiling and visibility variations were divided into VFR and IFR, runway uses were predetermined and correspond to the runway use with the maximum capacity, and aircraft mix was divided into five ranges as follows:

Aircraft Mix-- Percent (C+3D)
0- 20
21- 50
51- 80
81-120
121-180

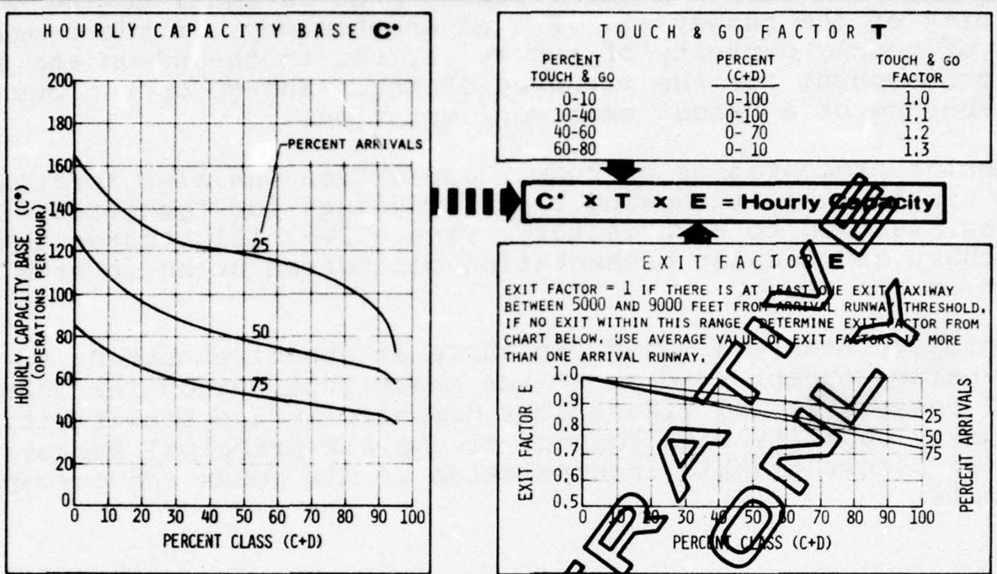


FIGURE 3-6. HOURLY CAPACITY OF RUNWAY USE DIAGRAM NOS. 8,9,72,73,74,75,76,77,114,115,116,117,118,119, FOR VFR CONDITIONS

PERCENT CLASS (C+D)	25 PERCENT ARRIVALS								50 PERCENT ARRIVALS								75 PERCENT ARRIVALS							
	EXITS BETWEEN 5000'-9000'				NO EXITS BETWEEN 5000'-9000'				EXITS BETWEEN 5000'-9000'				NO EXITS BETWEEN 5000'-9000'				EXITS BETWEEN 5000'-9000'				NO EXITS BETWEEN 5000'-9000'			
	PERCENT T+G				PERCENT T+G				PERCENT T+G				PERCENT T+G				PERCENT T+G				PERCENT T+G			
	0-10	10-40	40-60	60-80	0-10	10-40	40-60	60-80	0-10	10-40	40-60	60-80	0-10	10-40	40-60	60-80	0-10	10-40	40-60	60-80	0-10	10-40	40-60	60-80
0	165	182	198	215	165	182	198	215	[illegible]	142	155	[illegible]	129	142	155	168	85	94	102	111	85	94	102	111
10	144	158	173	187	142	156	170	185	109	[illegible]	[illegible]	142	106	117	127	138	74	81	89	96	72	79	86	94
20	132	145	158		128	141	154		96	106	115		91	100	109		65	72	78		61	67	73	
30	125	138	150		119	131	143		[illegible]	97	106		82	90	98		60	66	72		55	61	66	
40	121	133	145		[illegible]	[illegible]	137		83	91	100		75	83	90		56	62	67		50	55	60	
50	119	131	143		[illegible]	121	[illegible]		78	86	94		69	76	83		53	58	64		46	51	55	
60	116	128	[illegible]		106	117	[illegible]		75	83	90		64	70	77		50	55	60		42	46	50	
70	111	[illegible]	133		99	[illegible]	119		72	79	86		60	66	72		48	53	58		39	43	47	
80	[illegible]	[illegible]			91	100			69	77			56	62			46	51			36	40		
90	93	102			80	88			65	72			51	56			43	47			33	36		
100	60	66			51	56			43	47			33	36			31	34			23	25		

FIGURE 3-6. HOURLY CAPACITY OF RUNWAY USE DIAGRAM NOS. 8,9,72,73,74,75,76,77,114,115,116,117,118,119 FOR VFR CONDITIONS

FOR ILLUSTRATIVE PURPOSES ONLY

FIGURE IV-7. TYPICAL CHART AND TABULAR CONCEPTS

Because of the assumptions and determinations described above, it was possible to present runway capacity information in tabular form for different runway configurations, ceiling and visibility, and aircraft mixes as shown in Figure A1-1 of the Handbook.

Presentation of Gate Capacity Information. Gate capacity is affected significantly by the following factors:

- Number of gates
- Proportion of gates that can accommodate widebody aircraft
- Mix of aircraft requiring gate service
- Gate occupancy times

In Chapter 2 of the Handbook, the presentation of gate capacity information must account for the above factors and, at the same time, employ a concept similar to the concept for runway capacity information. The concept adopted for gate capacity presentation uses a capacity base that is calculated as a function of the gate mix of aircraft and gate occupancy times. The concept also uses a gate size factor that accounts for the proportion of gates that can accommodate widebody aircraft.

Presentation of Taxiway Capacity Information. The capacity of a taxiway crossing an active runway depends on a number of factors including:

- Distance of taxiway intersection from the departure end of the runway
- Runway flow rate
- Aircraft mix
- Percent arrivals

In Chapter 2 of the Handbook, the presentation of taxiway capacity information must account for the above factors and, at the same time, a concept similar to the concept for runway and gate capacity information. The concept adopted for taxiway capacity presentation uses charts that permit calculation of capacity as a function of the above factors.

Sensitivity tests performed in Phase II indicate that the capacity of a taxiway crossing an active runway is sensitive to the

occurrence of arrivals on the runway, so charts were produced, for runways with arrivals and runways without arrivals.

Capacity Production

The production of the capacity information was one of the final phases of Handbook development. Relevant assumptions and decisions concerning the overall production effort and related technical analyses are described in the following paragraphs.

Chapter 2 Production. In Chapter 2, production runs were performed for the three airfield components--runways, taxiways, and gates.

Runway Capacity Production. Production runs of the runway capacity model were made using input values, corresponding to the 11 principal factors, listed on Table IV-4. The inputs were derived from field data collected during Phase I and Phase II, and from discussions with air traffic controllers, FAA headquarters staff members, pilots, ATA personnel, and project team members.

Ceiling and Visibility. The ceilings and visibilities selected for VFR conditions permit simultaneous visual approaches to close spaced parallel runways; ceilings and visibilities selected for IFR ensure relief from the two-mile departure-arrival separation rule that exists when visibility is less than two miles. IFR capacities for poorer ceilings and visibilities are given in Appendix 2 of the Handbook.

Runway Use. As shown in Figure 2-2 of the Handbook, some 122 runway uses were selected for inclusion in Chapter 2.

Aircraft Mix. The six aircraft mixes selected for Chapter 2 production runs span a range of mix indexes between 0 and 180 and are representative of the kinds of aircraft mix currently experienced at U.S. airports.

Percent Arrivals. As noted previously, 40%, 50%, and 60% arrivals were used in the production of Chapter 2.

Table IV-4

RUNWAY CAPACITY MODEL INPUTS
Chapter 2 of Handbook

1. Ceiling and Visibility

VFR--3,500-foot ceiling, 5 miles visibility
IFR-- 800-foot ceiling, 2.5 miles visibility

2. Runway Use

See Figure 2-2 of Handbook.

3. Aircraft Mix

Mix No.	Percent Aircraft in Class A	B	C	D	Mix Index--Percent (C+3D)
1	95	5	0	0	0
2	60	30	0	0	0
3	40	35	20	5	35
4	30	30	30	10	60
5	15	15	55	15	100
6	0	10	45	45	180

4. Percent Arrivals

40%, 50%, and 60%

5. Percent Touch-and-Go

Percent Touch-and-Go	Mix Index--Percent (C+3D) 0	35	60	100/180
0	X[a]	X	X	--
10	X	X	X	--
20	X	X	X	--
30	X	X	--	--
40	X	--	--	--
50	X	--	--	--

a. X indicates production run performed.

6. Exit Configuration

Exits at 500 feet spacing up to 4,000 feet from the threshold and at 1,000 feet spacing thereafter on all arrival runways; for exit factor runs, see text for explanation.

7. ATC Rules and Procedures

Existing rules and procedures.[10]

8. Navigational Aids

Radar environment; at least one runway equipped with an instrument landing system (ILS).

9. Runway Restricted Use

All runways can accommodate the majority of all aircraft classes.

10. Aircraft Operating Characteristics

a. Approach Speed

Aircraft Class	Approach Speeds in Knots: Mix Nos. 1 and 2	Mix No. 3	Mix Nos. 4, 5, and 6
A	80	90	95
B	100	110	120
C	130	130	130
D	--	140	140

b. Jet Blast

Jet blast from arrival and departure aircraft on nonparallel runways are assumed not to influence runway capacity.

Table IV-4 (cont.)
RUNWAY CAPACITY MODEL INPUTS
Chapter 2 of Handbook

11. Length of Common Approach Path

Aircraft Class	Common Approach Path Length (nautical miles)	
	VFR	IFR
A	1	6
B	1	6
C	6	6
D	6	6

Percent Touch-and-Go Operations. As noted previously, a maximum of 50% touch-and-go operations is considered in Chapter 2.

Exit Configuration. In Chapter 2 it is assumed that, at a minimum, exits exist at each end of all runways. In addition, during Handbook production, runway capacities were calculated assuming as many exits as one at each 500-foot interval up to a distance of 4,000 feet from the threshold and one at each 1,000-foot interval thereafter on all arrival runways.

To determine the effect of exit configuration on capacity, and to produce appropriate exit factors for Handbook presentation, additional sets of model runs were made. The first step was to determine the runway occupancy time that would occur if there were no exits apart from those at the end of each runway. The second step involved the introduction of a single exit which was shifted down the runway in 750-foot increments. Arrival runway occupancy times were then computed for each location of the taxiway for use in capacity computations. As a result, a "range" of exit distances was identified within which capacity was significantly higher than for exits located outside the range. Finally, two, three, and four exits were located in different positions within this range for capacity production runs to determine exit factors.

ATC Rules and Procedures. Chapter 2 of the Handbook is based on existing ATC rules and procedures[10] and as observed in the Phase I and Phase II data collection activities. The effect of the rules and procedures is reflected in the field data collected, such as the time separations between aircraft (e.g., the time separations between successive departing aircraft using the same runway). Because ATC wake turbulence rules were modified in November 1975, the time separations ultimately adopted for Handbook production were based on field observations and refined to reflect these new wake turbulence rules and to represent the order of magnitude effect of ATC rules and procedures at a wide variety of high-activity airfields. However, because of variations from airport to airport these separations cannot or should not be construed as precise values for a particular airport. For example, the departure-departure separations in VFR conditions collected at Chicago O'Hare International Airport and San Francisco International Airport are tabulated on the following page.

Departure-Departure Separations (Seconds)
Chicago O'Hare International Airport

		Trail Aircraft Class C	Trail Aircraft Class D
Lead Aircraft	Class C	50	45
	Class D	120	90

Departure-Departure Separations (Seconds)
San Francisco International Airport

		Trail Aircraft Class C	Trail Aircraft Class D
Lead Aircraft	Class C	60	60
	Class D	85	90

From these data it is apparent that there are differences in the data among airports. Consequently, for purposes of Handbook production representative data were selected and used as the basis for departure-departure separations.

Navigational Aids. Analyses carried out in Phase II indicate that the greatest differences in capacity resulting from the availability of navigational aids probably concern the availability of a radar environment and/or a straight-in approach (usually an ILS).

In Chapter 2 of the Handbook, it is assumed there is a radar environment and an ILS on at least one arrival runway; the effect of the lack of either or both of these navigational aids in connection with certain runway uses is described in Appendix 3 of the Handbook.

Runway Restricted Use. The runway capacities presented in Chapter 2 of the Handbook are based on the assumption that all runways can be used by a majority of aircraft using an airport. At some airports, aircraft may be restricted from using a specific runway (referred to herein as "runway restricted use").

For example, such a restriction may be attributable to limited runway length or strength, insufficient lateral separation between a runway and a parallel taxiway, or aircraft noise abatement preferential runway procedures. Most frequently, such restrictions in the use of a runway apply to the larger, heavier aircraft using the airport. Appendix 5 deals with certain parallel runway uses where aircraft are restricted from using a particular runway.

Aircraft Operating Characteristics. Aircraft approach speeds were obtained principally from Phase I data. Because approach speed is a function of many different variables (e.g., landing weight, temperature, wind), the Phase I data showed a considerable amount of variation. See Figure I-11, Phase I Report. Analysis of these data, in addition to information obtained from air traffic controllers, aircraft manufacturers manuals, etc., led to the ground speeds utilized in the capacity production runs for Chapter 2 of the Handbook.

Arrival runway occupancy times also were derived from Phase I data. The data were correlated with exit taxiway locations at the particular airports as an integral step in Handbook production. As an example, the average arrival runway occupancy time data for aircraft using exits located at 4,000 feet and 5,000 feet from the arrival runway threshold are tabulated below:

Exit Taxiway Location (feet)	Arrival Runway Occupancy Time (seconds)			
	Class A	Class B	Class C	Class D
4,000	55	47	38	38
5,000	65	56	47	47

Length of Common Approach Path. In the computation of capacity by the model, the common approach path is defined as that path, followed by both lead and trail aircraft of an aircraft class pair, along which the air traffic controller has no means of speed control. It was found that even if a straight-in approach from 15 to 20 miles was used, speed control generally permitted the effective common approach path length to be of the order of six miles. In VFR conditions, small aircraft were observed to make short base approaches to many airports reducing the common approach path length to approximately one mile.

Runway Capacities Presented in Chapter 2. The results of the runway capacity production runs are shown in Table IV-5. These results in the table are hourly capacity bases that have to be multiplied by exit factors and touch-and-go factors to obtain hourly runway capacity.

Exit Factor. Exit factors for the basic runway uses were obtained by a two-step process. First, the appropriate runway capacity model was run for various exit distances. Second, the capacity values in the first step were divided by the capacity value associated with the maximum number of exits (i.e., exits at 500-foot spacing up to 4,000 feet from threshold and 1,000-foot spacing thereafter on all arrival runways) yielding exit factors.

Exit factors for runway uses other than Runway Use Nos. 1, 7, 9, 10, 11, 43 through 48, and 55 through 60 were obtained by a manual computation process. The exit factors obtained by this manual computation process are shown in Handbook Figures 2-3 through 2-64.

Touch-and-Go Factor. Touch-and-go factors for Runway Uses Nos. 1 and 9 were computed using the inputs described previously and are shown in Table IV-6. For other runway uses, a manual procedure described below was used to determine the touch-and-go factors.

For a runway use that does not have at least one runway used by mixed operations, touch-and-go operations are not possible and the touch-and-go factor is automatically 1.0 (e.g., Runway Use No. 2 in Chapter 2 of the Handbook).

For all other runway uses, the touch-and-go factor T is given by

$$T = \frac{C_{tx}}{C_x}$$

where

C_{tx} = the capacity of a runway use at x% arrivals and t% touch-and-go, and

C_x = the capacity of the same runway use at x% arrivals and 0% touch-and-go.

To determine C_{tx}, a combination of three runway operating strategies is necessary with each strategy being operated for a portion of the hour. These strategies are:

Table IV-5

HOURLY RUNWAY CAPACITY BASES
Chapter 2 of Handbook
(Operations per Hour)

Handbook Figure No.	Percent Arrivals	Mix Index--Percent (C+3D) 0	10	35	60	100	180
2-3	40	111	91	71	63	57	48
	50	105	86	68	61	55	49
	60	100	83	66	59	54	49
2-4	40	210	165	123	103	96	77
	50	168	132	99	82	77	70
	60	140	110	82	69	64	58
2-5	40	210	165	123	103	96	85
	50	168	132	99	82	77	70
	60	140	110	82	69	64	58
2-6	40	210	165	123	103	96	87
	50	168	132	99	82	77	70
	60	140	110	82	69	64	58
2-7	40	222	177	133	112	99	77
	50	211	168	127	108	97	81
	60	200	161	122	104	95	81
2-8	40	222	177	134	113	100	77
	50	211	168	128	109	98	82
	60	200	161	123	105	96	83
2-9	40	222	182	140	120	107	85
	50	211	173	133	116	105	88
	60	200	165	128	113	103	91
2-10	40	222	182	143	126	113	97
	50	211	173	137	121	111	98
	60	200	165	131	117	109	99
2-11	40	235	189	144	122	102	77
	50	282	227	173	146	123	92
	60	280	220	164	137	128	116

Table IV-5 (cont.)
HOURLY RUNWAY CAPACITY BASES

Handbook Figure No.	Percent Arrivals	Mix Index--Percent (C+3D) 0	10	35	60	100	180
2-12	40	333	267	203	172	151	113
	50	316	255	195	164	149	117
	60	280	220	164	137	128	116
2-13	40	333	267	205	175	156	129
	50	316	255	196	164	153	131
	60	280	220	164	137	128	116
2-14	40	333	267	204	174	155	127
	50	316	255	193	158	146	120
	60	280	220	161	132	122	100
2-15	40	333	267	202	171	151	114
	50	316	255	194	166	149	118
	60	301	243	186	161	147	122
2-16	40	333	267	205	175	156	129
	50	316	255	196	168	153	131
	60	301	243	187	162	149	130
2-17	40	333	267	203	170	150	113
	50	316	255	195	164	147	117
	60	301	243	185	159	144	121
2-18	40	333	272	203	172	151	120
	50	316	259	195	166	149	121
	60	301	248	186	161	147	122
2-19	40	333	272	210	183	164	133
	50	316	259	201	177	161	137
	60	301	248	193	171	158	140
2-20	40	420	330	246	206	192	154
	50	336	264	197	164	154	139
	60	280	220	164	137	128	116
2-21	40	420	330	246	206	192	166
	50	336	264	197	164	154	139
	60	280	220	164	137	128	116
2-22	40	444	353	267	225	199	154
	50	421	336	255	216	194	162
	60	401	321	243	200	186	158

Table IV-5 (cont.)
HOURLY RUNWAY CAPACITY BASES

Handbook Figure No.	Percent Arrivals	Mix Index--Percent (C+3D) 0	10	35	60	100	180
2-23	40	444	358	273	233	206	165
	50	421	341	262	225	202	166
	60	401	326	243	200	186	158
2-24	40	444	358	272	233	207	166
	50	421	341	261	226	203	171
	60	401	326	242	200	186	158
2-25	40	444	358	273	232	206	166
	50	421	341	262	224	201	171
	60	401	326	249	216	197	170
2-26	40	444	364	280	241	214	170
	50	421	346	266	233	210	176
	60	401	330	256	225	207	182
2-27	40	114	114	103	96	93	79
	50	109	114	99	82	77	70
	60	104	110	82	69	64	58
2-28	40	111	95	80	76	73	65
	50	105	92	77	77	76	70
	60	100	88	76	69	64	58
2-29	40	111	94	77	73	67	59
	50	105	90	75	73	69	63
	60	100	86	73	69	64	58
2-30	40	111	96	80	76	74	67
	50	105	93	78	77	77	70
	60	100	90	77	69	64	58
2-31	40	111	91	72	63	58	53
	50	105	86	69	61	58	56
	60	100	82	66	59	57	58
2-32	40	111	91	69	60	55	48
	50	105	86	66	58	53	48
	60	100	82	63	55	52	49
2-33	40	222	256	192	174	155	122
	50	210	262	184	150	138	117
	60	200	218	153	125	115	98
2-34	40	222	176	151	144	135	110
	50	210	166	147	145	138	117
	60	200	158	144	125	115	98

Table IV-5 (cont.)
HOURLY RUNWAY CAPACITY BASES

Handbook Figure No.	Percent Arrivals	Mix Index--Percent (C+3D) 0	10	35	60	100	180
2-35	40	222	176	141	135	125	107
	50	210	166	136	134	127	115
	60	200	158	131	125	115	98
2-36	40	222	176	144	143	136	111
	50	210	166	139	144	138	117
	60	200	158	134	125	115	98
2-37	40	222	176	129	114	109	104
	50	210	166	122	109	108	110
	60	200	158	116	105	106	98
2-38	40	222	176	128	110	101	94
	50	210	166	121	104	98	97
	60	200	158	115	100	95	98
2-39	40	222	182	151	144	135	110
	50	211	173	147	145	138	117
	60	200	165	144	125	115	98
2-40	40	333	272	211	184	164	138
	50	316	259	193	158	146	120
	60	280	220	161	132	122	100
2-41	40	420	330	241	198	182	126
	50	336	264	193	158	146	120
	60	280	220	161	132	122	100
2-42	40	420	330	240	198	182	150
	50	336	264	192	158	146	120
	60	280	220	160	132	122	100
2-43	40	69	62	59	56	53	47
	50	63	59	57	56	53	48
	60	52	50	47	46	49	49
2-44	40	79	74	71	70	73	74
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-45	40	79	74	71	70	73	76
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-46	40	79	77	71	76	78	74
	50	63	62	63	64	69	71
	60	52	52	53	54	58	65

Table IV-5 (cont.)
HOURLY RUNWAY CAPACITY BASES

Handbook Figure No.	Percent Arrivals	Mix Index--Percent (C+3D) 0	10	35	60	100	180
2-47	40	102	96	89	85	82	74
	50	101	94	88	84	82	76
	60	100	92	87	84	82	77
2-48	40	79	77	78	78	80	74
	50	63	62	63	65	70	78
	60	52	52	53	54	58	65
2-49	40	79	77	79	81	87	96
	50	63	62	63	65	70	78
	60	52	52	53	54	48	65
2-50	40	138	124	117	112	105	95
	50	126	119	114	111	105	96
	60	105	99	95	93	98	98
2-51	40	79	77	79	81	87	74
	50	63	62	63	65	70	78
	60	52	52	53	54	58	65
2-52	40	119	113	102	95	89	74
	50	126	119	114	111	106	89
	60	105	99	95	93	98	102
2-53	40	157	149	142	139	135	122
	50	126	119	114	111	117	122
	60	105	99	95	93	98	102
2-54	40	79	74	71	70	73	76
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-55	40	79	77	79	81	87	97
	50	63	62	63	65	70	78
	60	52	52	53	54	58	65
2-56	40	79	74	71	70	73	76
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-57	40	157	149	142	139	146	148
	50	126	119	114	111	117	122
	60	105	99	95	93	98	102
2-58	40	79	74	71	70	73	74
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51

Table IV-5 (cont.)
HOURLY RUNWAY CAPACITY BASES

Handbook Figure No.	Percent Arrivals	Mix Index--Percent (C+3D) 0	10	35	60	100	180
2-59	40	74	70	69	68	68	63
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-60	40	74	70	68	66	64	58
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-61	40	68	69	68	68	69	64
	50	63	59	57	56	59	61
	60	52	50	47	46	49	51
2-62	40	58	57	55	55	55	52
	50	55	54	54	54	55	55
	60	52	50	47	46	49	51
2-63	40	58	56	54	53	51	47
	50	55	54	52	51	50	47
	60	52	50	47	46	49	48
2-64	40	69	62	59	56	55	52
	50	63	59	57	56	55	55
	60	52	50	47	46	49	51

Table IV-6

TOUCH-AND-GO FACTORS AND CORRESPONDING HOURLY CAPACITIES
(Uncorrected for Effect of Exits)

TOUCH-AND-GO FACTORS

Percent Touch-and-Go	Mix Index 0			Mix Index 35			Mix Index 60		
	Percent Arrivals								
	40%	50%	60%	40%	50%	60%	40%	50%	60%
0%	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10%	1.05	1.05	1.05	1.05	1.05	1.04	1.04	1.04	1.04
20%	1.11	1.11	1.10	1.10	1.09	1.09	1.09	1.08	1.08
30%	1.18	1.17	1.16	1.16	1.15	1.14	--	--	--
40%	1.26	1.24	1.23	--	--	--	--	--	--
50%	1.34	1.32	1.30	--	--	--	--	--	--

HOURLY CAPACITY

Percent Touch-and-Go	Mix Index 0			Mix Index 35			Mix Index 60		
	Percent Arrivals								
	40%	50%	60%	40%	50%	60%	40%	50%	60%
0%	110.9	105.3	100.2	71.3	68.3	65.5	62.8	60.6	58.6
10%	116.9	110.6	105.0	74.6	71.4	68.3	65.4	63.0	60.9
20%	123.5	116.6	110.4	78.3	74.7	71.4	68.2	65.7	63.3
30%	131.0	123.2	116.3	82.4	78.4	74.8	--	--	--
40%	139.4	130.6	122.9	--	--	--	--	--	--
50%	149.0	139.0	130.3	--	--	--	--	--	--

a. The primary runway use with no touch-and-go operations

b. The primary runway use with touch-and-go operations on one of the runways, and

c. The secondary runway use strategy needed to satisfy percent arrivals specified.

Assume that strategy a is operated p of the time, and strategies b and c are operated r and q of the time, respectively. Then C_{tx} is obtained by solving the following simultaneous equations:

$$p + q + r = 1$$

$$x = \frac{pUC_u + r\frac{C_t}{2} + rC_a + qU'C_u'}{C_{tx}}$$

$$t = \frac{rC_t}{C_{tx}}$$

and

$$C_{tx} = pC_u + qC_u' + r\ (C_t + C_a + C_d)$$

where

C_u = the capacity of the primary runway use with arrivals separated by the minimum spacing allowable, and U is the corresponding percent arrivals.

C_t = the capacity of touch-and-go operations when all aircraft on the touch-and-go runway perform touch-and-go.

C_a = the arrival element of capacity associated with C_t (i.e., those operations on the non-touch-and-go runways).

C_d = the departure element of capacity associated with C_t (i.e., those operations on the non-touch-and-go runways).

C_u' = the capacity of the secondary runway use and u' is the corresponding percent arrivals.

Note that for four parallel runway uses, the maximum percent touch-and-go is approximately 30%.

<u>Relationship Between Exit Factor and Touch-and-Go Factor</u>. Initially, the exit factors and touch-and-go factors were computed independently; exit factors were computed assuming there were no touch-and-go operations, and touch-and-go factors were computed assuming that a "good" exit configuration exists (i.e., exit factor E = 1.0). Such an approach ignores the relationship between the touch-and-go and exit factors. For example, as the percent of touch-and-go operations increases, the effect of a poor exit configuration is reduced because touch-and-go operations do not require the use of exits.

Initially, three alternative methods for presentation of the interrelationship between exit factor and touch-and-go factor in Chapter 2 were investigated. These methods were:

- An equation correcting the exit factor (E)
- An equation correcting the touch-and-go factor
- An additional factor that combines both the effect of touch-and-go and exit configuration

None of these methods were acceptable because of their complexity. Therefore, a revised touch-and-go factor (i.e., reflecting the influence of exit configuration) was adopted based on a manual approach of average values computed for the touch-and-go factor that would occur with the best and worse exit systems.

The following is an example of the manual approach. For a single runway with 40% arrivals, 15% touch-and-go operations, and a mix index of 35%, the initial (i.e., uncorrected) touch-and-go factor (UT) is 1.08. For the same conditions, the exit factor equals 1.00 with the best exit system, and the exit factor equals 0.79 with the worst exit system. The average exit factor $\overline{E}$ is therefore (1 + 0.79) ÷ 2 = 0.89. The revised touch-and-go factor T* is then

$$T^* = \left[1 + \frac{(1 - \overline{E})\ (\%\ T\&G)}{100\overline{E}}\right] UT$$

$$= 1.10$$

Gate Capacity Production. Gate capacities were computed using the model described in the Phase I Report and the model inputs shown in Table IV-7. Gate capacity, for different gate mixes and non-widebody aircraft gate occupancy times, are shown in Table IV-8. Note that gate occupancy times include maneuvering time onto and off the gate during which time the gate is blocked from use by other aircraft. Table IV-9 shows the gate size factor computed for different percents of widebody aircraft and widebody gates.

Taxiway Intersection Capacity Production. The capacity of a taxiway crossing an active runway was computed using the model described in the User Manual and the model inputs shown in Table IV-10. The results of the model runs are shown in Table IV-11. These results were plotted in the graphs shown in Figures 2-65 and 2-66 of the Handbook, which are smoothed for ease of presentation and use.

Appendix 1 Production. In Appendix 1, hourly capacities in VFR and IFR conditions and annual service volumes for the 27 runway configurations and five mix index ranges are presented. The hourly runway capacity values were derived from the production runs for Chapter 2 of the Handbook, as follows:

Appendix 1 Mix No.	Appendix 1 Mix Index Range Percent (C+3D)	Chapter 2 Mix No.	Chapter 2 Mix Index--Percent (C+3D)
1	0- 20	1	0
		2	0
2	21- 50	3	35
3	51- 80	4	60
4	81-120	5	100
5	121-180	6	180

Capacity values for each mix index range used in Appendix 1 correspond to a specific mix index used in the production of Chapter 2, except for Appendix 1, Mix No. 1. The capacity values for Appendix 1, Mix No. 1 were computed by averaging the capacity values determined from Mixes Nos. 1 and 2 of the Chapter 2 production runs.

Table IV-7

GATE CAPACITY MODEL INPUTS

Gate Mix:[a] 0, 20, 40, 60, 80, and 100

Percent Widebody Gates: 10, 20, 40, 60, 80, and 100

Non-Widebody Gate Occupancy Time (minutes): 35, 40, 45, 50, 55, 60

R:[b] 1.0, 1.2, 1.4, 1.6

---

a. Percent of non-widebody aircraft.

b. $R = \frac{\text{Average gate occupancy time for widebody aircraft}}{\text{Average gate occupancy time for non-widebody aircraft}}$

Table IV-8

GATE CAPACITY BASE
Chapter 2 of Handbook
(Operations per Hour)

$R^a = 1.0$

Non-Widebody Gate Occupancy Time (minutes)	Gate Mix[b] 0	20	40	60	80	100
30	4.00	4.00	4.00	4.00	4.00	4.00
35	3.42	3.42	3.42	3.42	3.42	3.42
40	3.00	3.00	3.00	3.00	3.00	3.00
45	2.66	2.66	2.66	2.66	2.66	2.66
50	2.40	2.40	2.40	2.40	2.40	2.40
55	2.18	2.18	2.18	2.18	2.18	2.18
60	2.00	2.00	2.00	2.00	2.00	2.00

$R^a = 1.2$

Non-Widebody Gate Occupancy Time (minutes)	Gate Mix[b] 0	20	40	60	80	100
30	3.33	3.45	3.57	3.70	3.85	4.00
35	2.86	2.96	3.06	3.17	3.30	3.42
40	2.50	2.59	2.68	2.78	2.88	3.00
45	2.22	2.30	2.38	2.47	2.56	2.66
50	2.00	2.07	2.14	2.22	2.31	2.40
55	1.82	1.88	1.95	2.02	2.10	2.18
60	1.67	1.72	1.79	1.85	1.92	2.00

$R^a = 1.4$

Non-Widebody Gate Occupancy Time (minutes)	Gate Mix[b] 0	20	40	60	80	100
30	2.86	3.03	3.23	3.45	3.70	4.00
35	2.45	2.60	2.76	2.96	3.17	3.42
40	2.14	2.27	2.42	2.59	2.78	3.00
45	1.90	2.02	2.15	2.30	2.47	2.66
50	1.71	1.82	1.94	2.07	2.22	2.40
55	1.56	1.65	1.76	1.88	2.02	2.18
60	1.43	1.52	1.61	1.72	1.85	2.00

$R^a = 1.6$

Non-Widebody Gate Occupancy Time (minutes)	Gate Mix[b] 0	20	40	60	80	100
30	2.50	2.70	2.94	3.23	3.57	4.00
35	2.14	2.32	2.52	2.77	3.06	3.42
40	1.87	2.03	2.13	2.42	2.68	3.00
45	1.67	1.80	1.96	2.15	2.38	2.66
50	1.50	1.62	1.76	1.94	2.14	2.40
55	1.36	1.47	1.57	1.72	1.90	2.18
60	1.25	1.29	1.47	1.61	1.79	2.00

a. R is the ratio between gate occupancy times for widebody and non-widebody aircraft.
b. Percent non-widebody aircraft.

Table IV-9

GATE SIZE FACTOR
Chapter 2 of Handbook

Gate Mix	Percent of Gates That Accommodate Widebody Aircraft[a] 10	20	40	60	80	100
0	0.10	0.20	0.40	0.60	0.80	1.00
20	0.12	0.24	0.48	0.72	0.95	1.00
40	0.15	0.30	0.61	0.91	1.00	1.00
60	0.22	0.43	0.86	1.00	1.00	1.00
80	0.41	0.82	1.00	1.00	1.00	1.00
100	1.00	1.00	1.00	1.00	1.00	1.00

a. Computed for R = 1.3 using

$$S = \text{Min}\left[\frac{g(1.3 - 0.3M)}{1.3(1 - M)}, 1\right]$$

where

S is gate size factor.

g is proportion of gates that can accommodate widebody aircraft.

M is the gate mix divided by 100, i.e., the proportion of non-widebody aircraft in the mix.

Table IV-10

RUNWAY-TAXIWAY INTERSECTION MODEL INPUTS[a]

Headway Between Taxiing Aircraft (H)

200 ft (between general aviation aircraft)
750 ft (between air carrier aircraft)

Aircraft Size (A)

Class A	25 ft
Class B	50 ft
Class C	150 ft
Class D	200 ft

Runway Clearance Distance (nose-in through tail-out) (R)

General Aviation Aircraft	200 ft
Air Carrier Aircraft	450 ft

Taxi Speed (T)

10 mph	(across general aviation runway)	14.7 ft/sec
15 mph	(across air carrier runway)	22.0 ft/sec

Inputs for Each Mix

Mix No.	T (mph)	A (ft)	R (ft)	H (ft)
1	10	25	200	200
2	12	50	250	300
3	12	75	300	350
4	15	120	350	400
5	15	150	450	600
6	15	175	450	700

Table IV-10 (cont.)
RUNWAY-TAXIWAY INTERSECTION
MODEL INPUTS

Runway-Taxiway Intersection Clearance Time

Intersection Distance (feet)	Aircraft Class	Arrival-Taxi Clearance Time (seconds)		Departure-Taxi Clearance Time (seconds)		Arrival-Taxi Separation (seconds)
		Mean	Buffer	Mean	Buffer	
0	A	0	10	0	10	55
	B	0	10	0	10	55
	C	0	10	0	10	55
	D	0	10	0	10	55
1,000	A	17	10	13	10	49
	B	8	10	13	10	49
	C	6	10	12	10	49
	D	5	10	12	10	49
2,000	A	32	10	23	10	43
	B	23	10	20	10	43
	C	12	10	20	10	43
	D	11	10	20	10	43
4,000	A	32	10	29	10	30
	B	40	10	32	10	30
	C	38	10	30	10	30
	D	35	10	30	10	30

---

a. Notation similar to those in User Manual.

Table IV-11

RUNWAY-TAXIWAY INTERSECTION CAPACITY
Chapter 2 of Handbook
(Operations per Hour)

		Intersection Distance (feet)							
		0		1,000		2,000		4,000	
Mix Index-- Percent (C+3D)	Arrivals Runway Flow Rate	Without Arrivals	With Arrivals	Without Arrivals	With Arrivals	Without Arrivals	With Arrivals	Without Arrivals	With Arrivals
0	20	245	205	230	190	215	185	210	190
	45	225	135	185	100	150	85	145	100
	65	210	80	145	25	100	5	95	30
	85	190	65	110	15	55	--	45	--
10	20	200	165	185	155	175	146	170	150
	45	185	110	150	85	125	65	115	75
	65	175	70	125	30	90	--	70	15
	85	160	65	95	35	55	--	25	--
35	20	170	140	160	135	150	125	140	125
	45	155	95	125	75	105	55	85	55
	65	145	55	100	30	75	10	45	--
	85	130	60	80	40	45	--	10	--
100	20	125	105	115	100	110	95	105	90
	45	115	70	95	60	80	50	65	35
	65	--	45	--	35	--	25	--	--
	85	--	--	--	--	--	--	--	--
180	20	110	90	100	90	95	85	90	80
	45	105	65	85	55	75	50	60	45
	65	--	50	--	40	--	35	--	--
	85	--	--	--	--	--	--	--	--

The touch-and-go factors used for developing information in Appendix 1 were derived from the touch-and-go factors produced during the Chapter 2 capacity production runs by selecting the touch-and-go factor associated with the correct percent touch-and-go range and applicable mix index. The appropriate touch-and-go factors were applied to the capacities associated with the different runway uses that can be accommodated by the runway configuration. The maximum capacity for these different runway uses is presented in Figure A1-1 of the Handbook.

The annual service volumes shown on Figure A1-1 of the Handbook are based on the following assumptions:

1. IFR conditions occur 10% annually.

2. The utilization of the runways which produces the largest hourly capacity is assumed to occur 80% of the year. An alternative utilization of the runway which produces a smaller capacity is assumed to occur 20% of the year. A complete listing of runway utilization assumptions is given in Table IV-12.

   The following values of D and H were assumed for the mix indices shown in Handbook Figure A1-1:

Percent (C+3D)	D	H
0 to 20	290	9
21 to 50	300	10
51 to 80	310	11
81 to 120	320	12
121 to 180	350	14

The ranges of annual delay values shown in the Handbook are based on the calculations performed in support of annual service volume development described earlier in this chapter (the range of annual delay values is presented in Figure IV-2).

<u>Appendix 2 Production</u>. Appendix 2 contains hourly runway capacities of certain runway uses under poor visibility and ceiling conditions (PVC) that are slightly above airport operating minima.

Table IV-12

RUNWAY UTILIZATION ASSUMPTIONS FOR ANNUAL SERVICE VOLUME CALCULATIONS

Runway Configuration	Maximum Capacity Runway Use[a] (Diagram Number From Handbook Figure 2-2)	Secondary Runway Use[b] (Diagram Number From Handbook Figure 2-2)
1	1	1
2	9	2
3	10	2
4	11	2
5	12	2
6	29	15
7	30	16
8	31	17
9	42	32
10	44	1
11	68	2
12	69	2
13	70	2
14	71	2
15	56	2
16	74	1
17	73	1
18	86	2
19	9	2
20	94	2
21	93	2
22	99	1
23	98	1
24	111	2
25	9	2
26	119	2
27	118	2

a. Used 80% of the year.
b. Used 20% of the year.

The input assumptions for the production runs are identical with those used in Chapter 2 of the Handbook with the following principal exceptions. Strict application of ATC rules and procedures followed under very low ceiling and visibility conditions were assumed for Appendix 2 production runs. For example, no visual relief is allowed from the two-mile departure-arrival separation rule, and arrival runway occupancy times were increased by some 10 seconds to reflect use of ASDE in poor visibility and ceiling conditions.

The results of the production runs are presented in Appendix 2 of the Handbook.

Appendix 3 Production. Appendix 3 contains hourly runway capacities of certain runway uses in IFR conditions that would occur with runway uses in the absence of the navigational aids or ATC equipment assumed in Chapter 2.

The assumptions for the production runs were obtained by review of ATC rules and procedures,[10] and discussions with pilots and air traffic control specialists. It was determined that while there are many factors that influence runway capacity in the absence of the assumed ATC or navigational equipment, the most significant differences in capacity are associated with straight-in or circling approaches and radar or nonradar environments.

With straight-in approaches and a radar environment, the inputs are the same as those presented in Chapter 2 of the Handbook.

With circling approaches and a radar environment, discussions with air traffic controllers indicated that an additional distance separation should be added to separations between arrivals.

With straight-in approaches a nonradar environment, a time separation rule applied.[10] An additional buffer time is added to the separation between arrivals to account for variations in (1) time over the final approach fix, (2) the length of the common approach path, and (3) approach speeds of different aircraft classes.

With circling approaches and a nonradar environment, it was determined that controllers tend to use a larger separation between arrivals than that specified by ATC rules[10] to ensure safe operations. Because of this large separation between arrivals, it was assumed that departures can be interleaved between arrivals without causing additional separation requirements.

Runway capacity information presented in Appendix 3 was obtained either from direct application of the runway capacity models or by a manual calculation based on assumed separations between aircraft. In the manual calculation, runway capacity was computed in accordance with the following formula:

$$\text{Runway Capacity} = \frac{1}{\overline{T}}$$

where

$\overline{T}$ = the weighted average time separation between successive arrivals

The time separations used in the calculation of $\overline{T}$ were weighted according to the proportions of the aircraft classes in the different aircraft mixes identified in Table IV-4. The results of the production runs are presented in Appendix 3 of the Handbook.

Appendix 4 Production. Appendix 4 contains hourly runway capacities for a single runway that has less than the minimum exits assumed in Chapter 2.

As noted previously, Appendix 4 contains runway capacity information for a single runway used by an aircraft mix of 90% Class A, 10% Class B, and 50% arrivals. Two groups of percent touch-and-go operations (0% to 25% and 26% to 50%) were employed to demonstrate the effect of the relationship between exit configuration and touch-and-go operations. A runway length was assumed, corresponding to a basic utility Stage II airport at standard temperature and pressure.[15]

The effect of an exit configuration with less than the minimum exits assumed in Chapter 2 is to increase runway occupancy times for arrivals and departures and, thus, reduce capacity. To compute the effect on capacity, it was assumed that aircraft would taxi at normal taxi speeds on the runway if an appropriate exit were not available. Mean runway occupancy times used as inputs to the runway capacity models in production of Appendix 4 are given in Table IV-13. The time separations used in the calculation of $\overline{T}$ reflect the exit configuration, normal taxi speeds, and the assumptions made concerning ATC procedures and equipment noted above. For example for Configuration No. 1 in Appendix 4, departure runway occupancy times were the same as used in Chapter 2. Arrival runway occupancy times were derived by adding: (1) the time assumed necessary to perform an 180° turn on the runway, (2) the time to taxi to the exit, and (3) the arrival runway occupancy times used in Chapter 2.

Table IV-13

RUNWAY OCCUPANCY TIMES FOR APPENDIX 4 PRODUCTION

Runway Configuration Number	Arrival Runway Occupancy Time (seconds)		Departure Runway Occupancy Time (seconds)	
	Class A	Class B	Class A	Class B
1	94	133	28	24
2	48	88	63	24
3	42	33	128	124
4	48	88	28	24
5	38	73	52	24
6	39	33	72	68

Additional assumptions were made concerning ATC procedures and equipment in computing the capacities of the single runway in IFR conditions:

- No air traffic control tower
- Radio communications between aircraft and air route traffic control center
- Air route traffic control center providing approach control
- Airport control zone

Examination of ATC rules and procedures, and discussions with FAA air traffic control specialists indicated that an arrival would not be allowed to cross the final approach fix until the previous aircraft reports being off the runway. This implies that separations between arrivals are at least equal to the travel time from the final approach fix to the runway threshold plus the time the runway is occupied.

Based on the above, capacity computations were performed for the single runway *in IFR conditions* using a manual technique. Runway capacity was calculated in accordance with the following formula:

$$\text{Runway Capacity} = \frac{1}{\overline{T}}$$

where

$\overline{T}$ = the weighted average time separation between successive arrivals

The results of the production runs are presented in Appendix 4 of the Handbook.

Appendix 5 Production. Appendix 5 contains hourly capacities for runway uses that allow mixed operations on all runways. In the appendix, it is assumed that one of the runways is restricted, i.e., it cannot accommodate aircraft of Classes C and D. This restriction guided the selection of aircraft mixes used in Appendix 5 production. All other inputs are the same as those used in Chapter 2 production.

To determine capacity, the runway capacity model was operated using a different mix on each runway. A total flow rate was obtained, and an airfield mix was manually computed. This was repeated with different runway specific mixes which were selected to achieve the appropriate airfield mix. For any given mix index and percent arrivals, two capacities were used as upper and lower bounds. The upper bound is the capacity corresponding to that with no runway restricted use. The lower bound is the capacity that would exist if the restricted runway was eliminated from the runway use. The correct capacity was then obtained by an interactive process that yields a result which was within the bounds and at the same time achieved the appropriate airfield mix.

Data Reduction Procedures for Model Inputs. The model inputs used in Handbook production and in model validation as described in this report were obtained from Phase I and Phase II data, discussions with FAA air traffic control specialists, examination of ATC rules, and project team judgments.

The procedure used in reducing and analyzing the field data was as follows. The raw field data were summarized by individual data sets. These data sets were then reviewed to define data sets that could be combined or "merged," i.e., data sets collected under similar conditions of specified weather and physical phenomena were merged. Following the merging of the data sets, significance tests were performed to determine whether significant differences in airfield operations are created by various types of conditions on the airport (such as varying weather conditions, night versus day) or by variations in types of aircraft and their behavior on the airfield.

Based on the review of the data reduction output and the significance tests, appropriate data sets were selected for each model parameter from the total set of data for all airports. The rationale used in the selection of the data sets included consideration of the following criteria: data applicability and significance, sample size, airfield operating conditions, and aircraft demand. An example of the data analysis performed to select production inputs is described below.

Phase I and Phase II data were reduced using computer programs that produced a frequency distribution of appropriate time separations by airport and by weather conditions. However, in several cases, it was necessary to apply a heuristic approach to data analysis. Such an approach involves professional judgment in the evaluation of the output of such computer programs because of insights concerning the collection of the raw data, knowledge

of statistics related to sample sizes, and the like. For example, Figure IV-8 shows a typical frequency distribution output from a data reduction computer program. On the figure, the "tail" of the distribution is quite large (in this case, the project team was aware that this was caused by data collected during low demand periods) which indicates a bias away from the normal distribution. However, it is apparent that the portion of the distribution on the "lower separation side" has a shape that closely resembles a normal distribution. Therefore, in this example, the analysis technique used to obtain reasonable minimums and standard deviations of separations was to examine the "lower separation side" of the frequency distribution and compare it with the curve shapes of a normal distribution with different standard deviations. The most similar normal distribution was selected as applicable.

Similarly, it should be noted that the Phase I and Phase II data were not complete for all aircraft classes and operations type pairs. In such cases, judgments were based on "comparable" data that had a significant sample size. In some cases, no "comparable" data were available; in these situations, assumptions based on ATC rules, project team judgment, etc., were made.

The reasonableness of this approach to data reduction is supported by the successful capacity and delay model validation process described in Chapter III of this report.

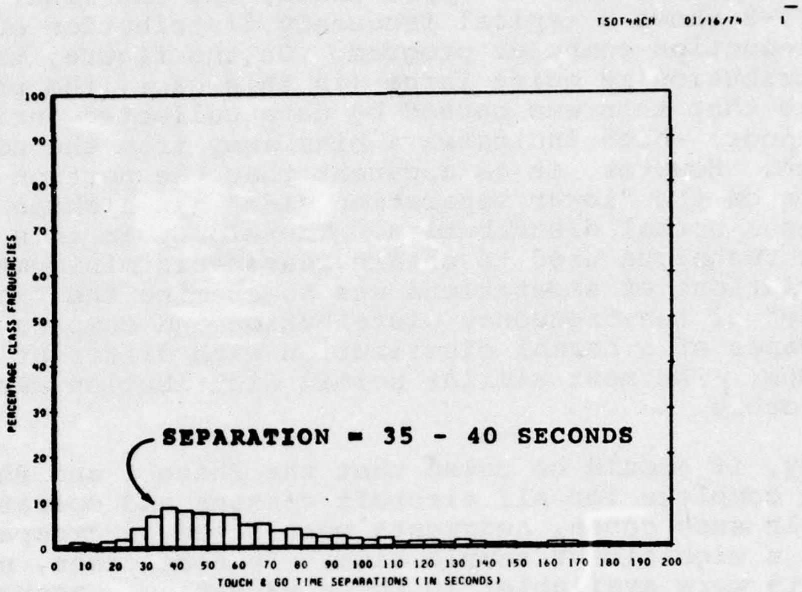
Presentation of Delay

Delay to aircraft can be thought of as the result of two types of oversaturation--general oversaturation and noise oversaturation.

- General oversaturation occurs when the general "deterministic" demand of scheduled aircraft operations is greater than the capacity of the component for an extended period of time, usually greater than one hour.

- Noise oversaturation occurs when the deviation from the expected times of operations cause demand to exceed capacity for a short period of time, usually less than one hour.

The magnitude of delays occurring due to noise oversaturation are normally much smaller than delays occurring due to the general oversaturation, as illustrated by the relative size of the shaded areas in Figure IV-9.



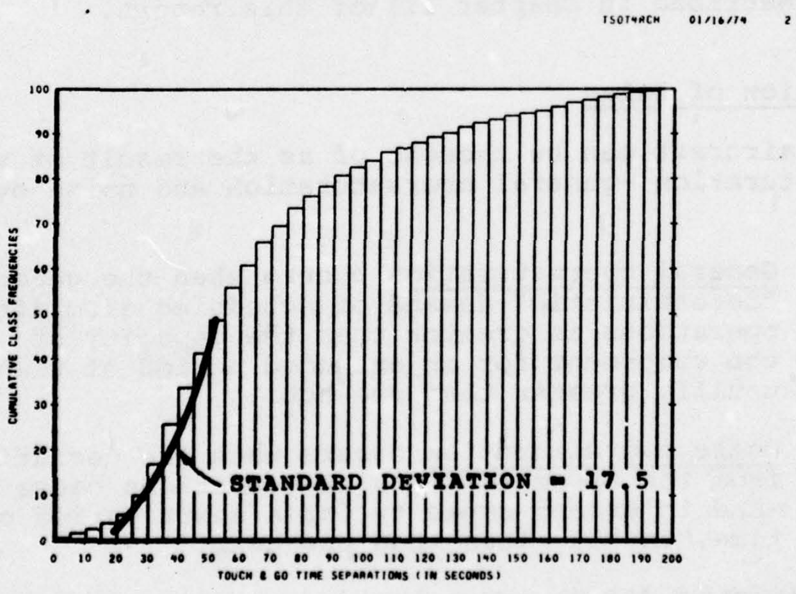


FIGURE IV-8. TYPICAL DISTRIBUTIONS OF SEPARATIONS

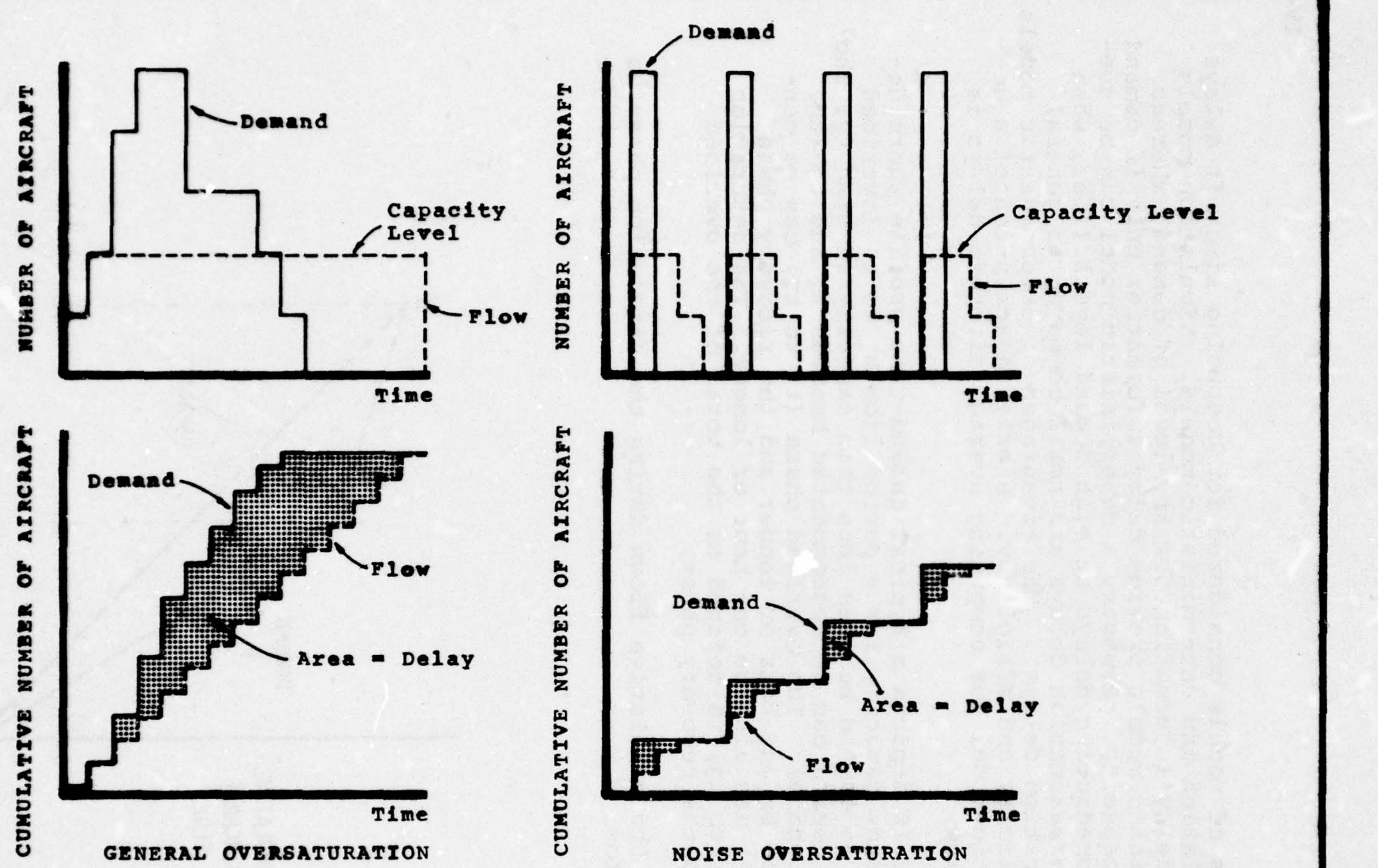
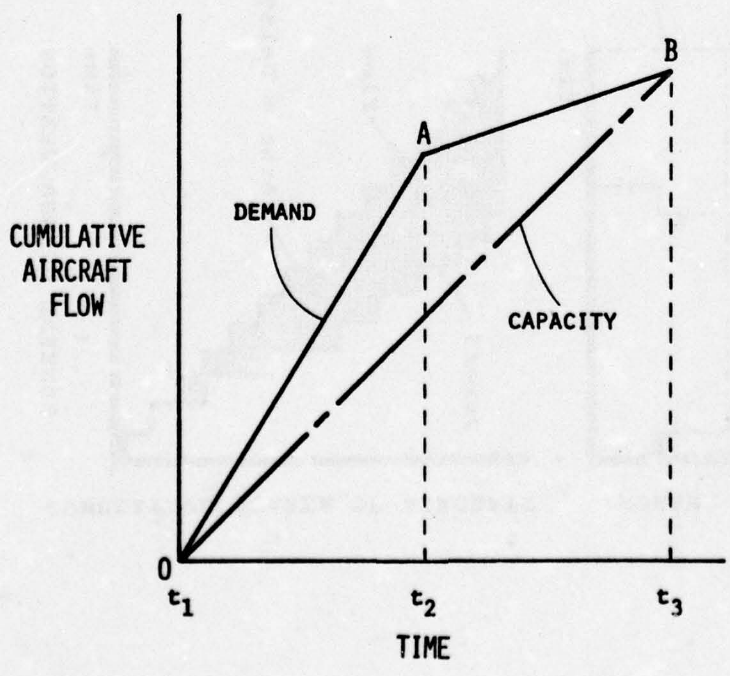


FIGURE IV-9. ILLUSTRATION OF GENERAL AND NOISE OVERSATURATION DELAYS

Two kinds of models considered for computing aircraft delays are simulation and deterministic models. Simulation models provide delay information for any level of demand, whereas deterministic models provide delay information only if demand exceeds capacity. However, a deterministic model can be useful for predicting delays at high demand levels (i.e., when noise oversaturation delays are small compared to general oversaturation delays). The advantages of deterministic models are simplicity and efficiency. A brief description of a deterministic model for computing average aircraft delays is given below.

Figure IV-10 depicts a typical demand-time profile where demand exceeds capacity for a period from t_1 to t_2 (overload phase). As demand becomes less than capacity at time t_2, the overload demand can be accommodated between t_2 and t_3 (the recovery phase). The overload phase (t_1 to t_2) can be considered to be one hour or longer and the recovery phase (t_2 to t_3) may also be one hour or longer. The saturation phase (t_1 to t_3) is defined as the total of the overload phase and the recovery phase.

Consider the cumulative flows during the saturation phase as shown below:



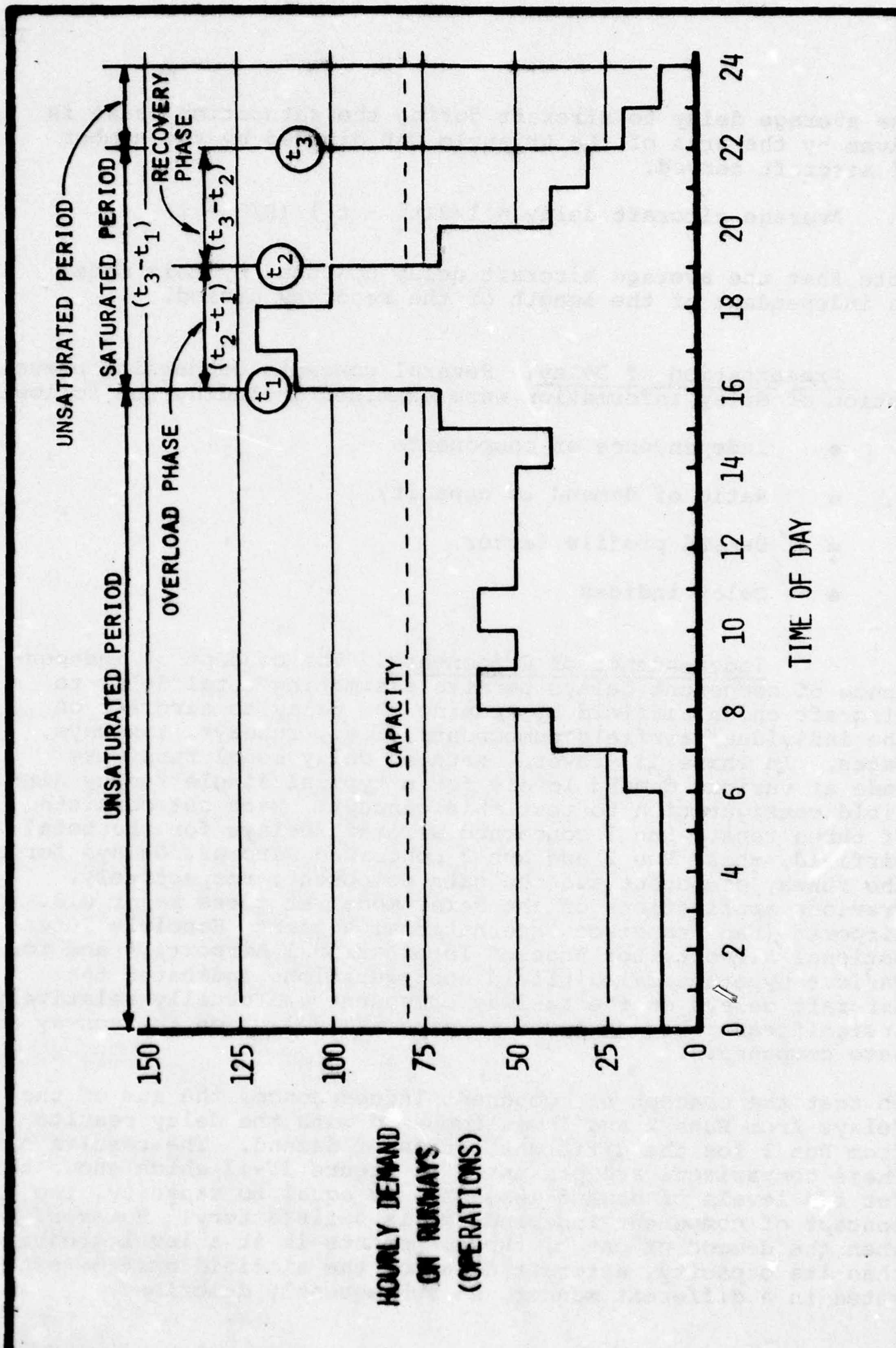


FIGURE IV-10. DEFINITION OF OVERLOAD, RECOVERY, AND SATURATION PHASES

The average delay to aircraft during the saturation phase is given by the area of the triangle OAB divided by the number of aircraft served.

$$\text{Average aircraft delay} = 1/2(t_2 - t_1)\ (D/C - 1)$$

Note that the average aircraft delay computed by this model is independent of the length of the recovery period.

Presentation of Delay. Several concepts concerning presentation of delay information were examined including the following:

- Independence of components
- Ratio of demand to capacity
- Demand profile factor
- Delay indices

Independence of Components. The concept of independence of component delays permits estimating total delay to aircraft on an airfield by summing the delay to aircraft on the individual airfield components, i.e., runways, taxiways, gates. In Phase II, several sets of delay model runs were made at various demand levels for a typical single runway airfield configuration to test this concept. Each set consisted of three runs. Run 1 concerned aircraft delays for the total airfield, while Run 2 and Run 3 concerned aircraft delays for the runway component and the gate component, respectively. Previous applications of the delay model at three major U.S. airports (San Francisco International Airport, Honolulu International Airport, Los Angeles International Airport),* and for various hypothetical airfield configurations indicated that aircraft delays on the taxiway component are usually relatively insignificant when compared to aircraft delays on the runway and gate components.

To test the concept of component independence, the sum of the delays from Runs 2 and 3 was compared with the delay results from Run 1 for the different levels of demand. The results of these comparisons are presented in Figure IV-11 which shows that for two levels of demand less than or equal to capacity, the concept of component independence is satisfactory. However, when the demand or one of the components is at a level greater than its capacity, aircraft delay on the airfield must be estimated in a different manner, as subsequently described.

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*On other assignments.

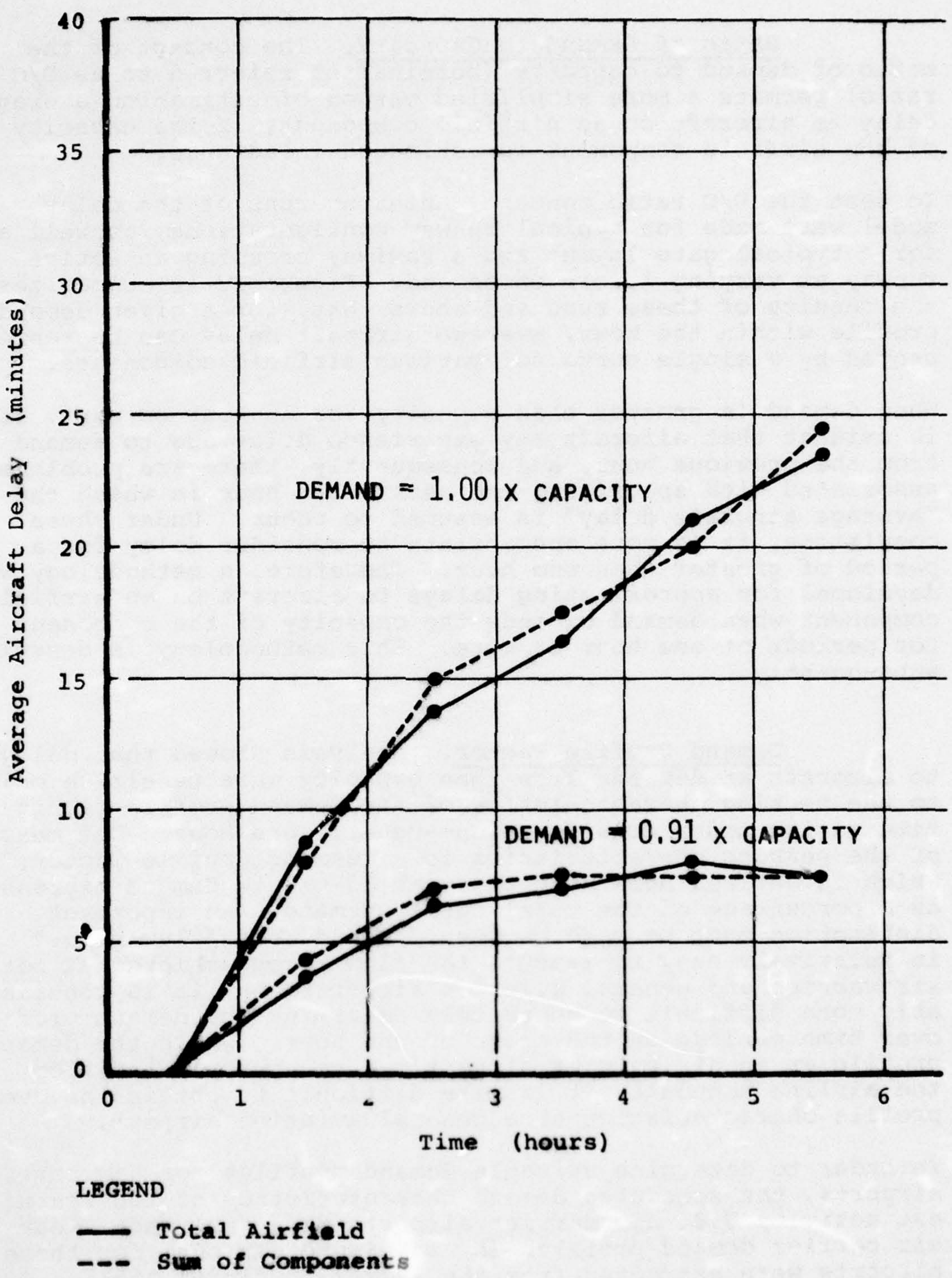


FIGURE IV-11. COMPONENT INDEPENDENCE TEST

Ratio of Demand to Capacity. The concept of the ratio of demand to capacity (hereinafter referred to as D/C ratio) permits a more simplified method of estimating average delay to aircraft on an airfield component, if the capacity of the airfield component is estimated in advance.

To test the D/C ratio concept, numerous runs of the delay model were made for typical runway configurations, as well as for a typical gate layout and a taxiway crossing an active runway at varying levels of demand. Figure IV-12 summarizes the results of these runs and shows that, for a given demand profile within the hour, average aircraft delay can be represented by a single curve for various airfield components.

When demand is greater than capacity for an hour or more, it is evident that aircraft may experience delay due to demand from the previous hour, and consequently, there are problems associated with specifying the particular hour in which the "average aircraft delay" is assumed to occur. Under these conditions, it is more appropriate to consider delay for a period of greater than one hour. Therefore, a methodology was developed for approximating delays to aircraft on an airfield component when demand exceeds the capacity of the component for periods of one hour or more. This methodology is described subsequently.

Demand Profile Factor. Analysis showed that delays to aircraft at demands less than capacity were sensitive only to the peaking characteristics of the demand profile within the time period under consideration--usually one hour. One measure of the peaking characteristics is a "demand profile factor," which is defined herein as the peak 15-minute demand expressed as a percentage of the total hourly demand. An important distinction must be made between "demand" and "flow rate." It is relatively easy to measure the flow rates achieved at both air carrier and general aviation airports, but it is considerably more difficult to accurately determine the demand profile over time periods on the order of one hour. While the demand profile at an air carrier airport can be approximated from the airline schedule, it is more difficult to obtain the demand profile characteristics at a general aviation airport.

In order to determine suitable demand profiles for air carrier airports, the scheduled demand characteristics of the ten highest activity U.S. air carrier airports were analyzed. Peak hour air carrier demand profiles (by 15-minute periods) for these airports were extracted from the 1972-73 Official Airline Guide (OAG) listings.

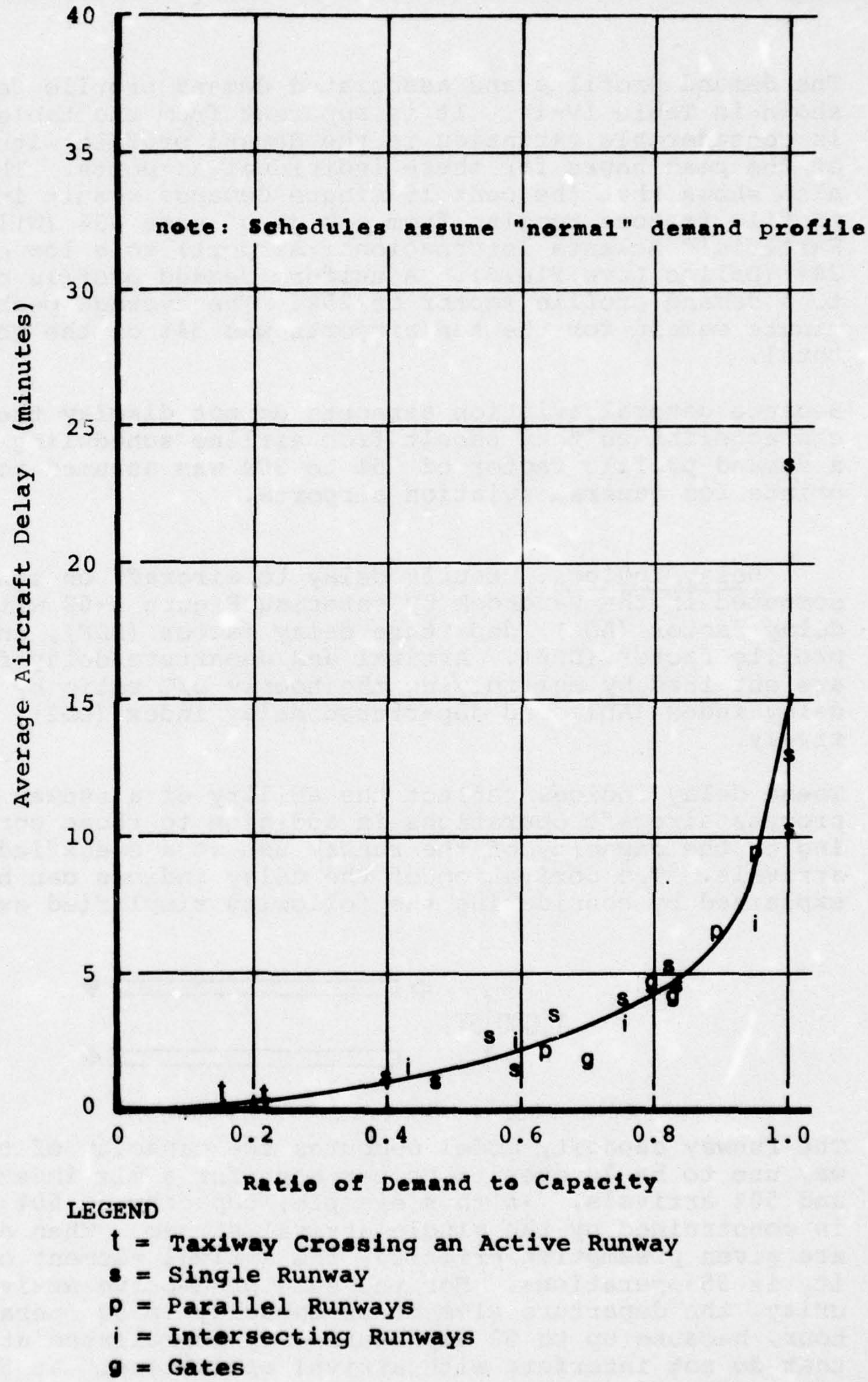


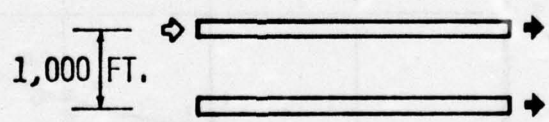
FIGURE IV-12. RATIO OF DEMAND TO CAPACITY TEST

The demand profiles and associated demand profile factors are shown in Table IV-14. It is apparent from the table that there is considerable variation in the demand profile within each of the peak hours for these individual airports. The table also shows that the peak 15-minute demands result in demand profile factors ranging from a high of some 45% (William B. Hartsfield Atlanta International Airport) to a low of some 28% (Dallas Love Field). A uniform demand profile corresponds to a demand profile factor of 25%. The average peak 15-minute demand for the ten airports was 34% of the hourly total.

Because general aviation airports do not display the peaking characteristics that result from airline scheduling practices, a demand profile factor of 25% to 30% was assumed to be appropriate for general aviation airports.

<u>Delay Indices</u>. Hourly delay to aircraft on runways is computed in the Handbook by entering Figure 2-68 with arrival delay factor (ADF), departure delay factor (DDF), and demand profile factor (DPF). Arrival and departure delay factors are obtained by multiplying the hourly D/C ratio by arrival delay index (ADI) and departured delay index (DDI), respectively.

These delay indices reflect the ability of a runway use to process aircraft operations in addition to those corresponding to the capacity of the runway use at a specified percent arrivals. The derivation of the delay indices can best be explained by considering the following simplified example:



The runway capacity model computes the capacity of this runway use to be 70 operations per hour for a mix index of 180 and 50% arrivals. In this example, capacity at 50% arrivals is constrained by the single arrival stream. When arrivals are given preemptive priority, the arrival element of capacity is 35 operations. For the same preemptive arrival priority, the departure element of capacity is 50 operations per hour, because up to 50 departures may be released at times that do not interfere with arrival operations. At 50% arrivals, only 35 of these departures are required to balance the 35 arrival aircraft, and capacity at 50% arrivals is 35 arrivals plus 35 departures, or 70 operations per hour.

Table IV-14

PEAK HOUR DEMAND PROFILES--SCHEDULED OPERATIONS

	Percent of Peak Hour Demand in 15-Minute Periods				
Airport	0-14 Minutes	15-29 Minutes	30-44 Minutes	45-59 Minutes	Demand Profile Factor
ORD	20	24	26	30	30%
LAX	28	15	24	33	33
ATL	18	45	25	12	45
JFK	33	19	29	19	33
DAL	25	22	28	25	28
LGA	19	19	22	40	40
SFO	27	10	32	31	32
DCA	12	20	33	35	35
BOS	30	16	27	27	30
MIA	33	18	25	24	33
				Average	34%
				Range	28% to 45%

Source: 1972-1973 Official Airline Guide.

The 15 (i.e., 50 - 35) "excess" departures are not needed for capacity at 50% arrivals, but represent available departure gaps that can reduce departure delays. Therefore, in the computation of delay, it is necessary to take all available gaps into account and to determine arrival and departure elements of delay separately. In this way arrival and departure demands can be correctly combined with appropriate arrival and departure elements of capacity to compute aircraft delays.

Continuing the example, the arrival element of capacity is 35, while the departure element of capacity is 50 operations per hour. With a demand of 70 operations per hour (35 arrivals and 35 departures) the arrival delay factor

$$ADF = \frac{35}{35} = 1.0,$$

while the departure delay factor

$$DDF = \frac{35}{50} = 0.7.$$

Because ADF and DDF are defined by

$$ADF = ADI \times (D/C)$$

$$DDF = DDI \times (D/C)$$

Therefore, in this simplified example where the hourly D/C ratio is 70 ÷ 70 = 1.0,

$$ADI = \frac{ADF}{(D/C)} = \frac{1.0}{1.0} = 1.0$$

and

$$DDI = \frac{DDF}{(D/C)} = \frac{0.7}{1.0} = 0.7$$

Because DDI and hence DDF reduce, delays to departing aircraft reduce correspondingly. With other numerical examples, ADI and hence ADF would reduce, causing delays to arriving aircraft to reduce correspondingly.

A further influence on aircraft delay is the impact of arrival demand on the departure element of capacity. For certain combinations of runway use, mix index and percent arrivals, the existence of an arrival demand less than the arrival element of capacity can cause the departure element of capacity to increase. This feature can be illustrated by expanding the previous simplified example to account for this further influence by reducing the demand to a level below capacity.

With a demand of 50 operations per hour (25 arrivals and 25 departures), the arrival demand (25) is less than the arrival element of capacity (35).

The ten arrival gaps that are not utilized by arrivals (due to absence of arrival demand) are available for departures thereby effectively increasing the departure element of capacity and reducing departure delay.

A set of equations was developed to take the above mentioned factors into account. The equations define an arrival delay index (ADI) and a departure delay index (DDI) which are used in the computation of the delay factor.

To derive ADI and DDI, the first step was to define the following variables:

D_a = hourly arrival demand

D_d = hourly departure demand

D = total hourly demand

C_a = arrival element of hourly capacity

C_d = departure element of hourly capacity

C_x = hourly capacity at X percent arrivals

C_u = hourly capacity corresponding to U percent arrivals

C_o = hourly capacity at 0 percent arrivals

U = percent arrivals with basic runway use and with preemptive arrival priority

C_u' = hourly capacity corresponding to U' percent arrivals

U' = percent arrivals with arrival priority for modified runway use with arrival streams removed that would reduce departures

For computation of ADI and DDI a controller operating strategy is assumed that minimizes arrival delays as long as departures are not penalized excessively. In mathematical terms, ADI is minimized subject to DDI ≤ 1.

Therefore, it is first necessary to check whether DDI ≤ 1 using the preemptive arrival priority operating strategy with U percent arrivals (i.e., to minimize arrival delays) by computing DDI as follows:

$$\text{DDI} = \frac{\frac{D_d}{C_d}}{\frac{D}{C_x}} = \left[\frac{(1 - X)D}{C_d}\right]\left[\frac{C_x}{D}\right] = \frac{(1 - X)C_x}{C_d}$$

C_d depends on whether or not $\frac{D_a}{C_a} \leq 1$ (i.e., whether there are arrival gaps that can be used to increase the departure element of capacity).

(a) If $\frac{D_a}{C_a} \leq 1$, then C_d is computed as follows:

$$C_d = \frac{D_a}{C_a}(1 - U)\ C_u + (1 - \frac{D_a}{C_a})\ C_o$$

where

$$\frac{D_a}{C_a} = \frac{XD}{UC_u} = \frac{XC_x}{UC_u} \cdot \frac{D}{C_x}$$

Then using the equations above, compute $\text{DDI} = \frac{(1 - X)\ C_x}{C_d}$.

If DDI ≤ 1, then $\text{ADI} = \frac{\frac{D_a}{C_a}}{\frac{D}{C_x}} = \frac{XC_x}{UC_u}$

If DDI > 1, combine strategies operating at U percent arrivals q of the hour and U' percent arrivals (1 - q) of the hour to ensure that DDI is reset to 1, and solve for ADI as follows:

$$ADI = \frac{XC_x}{C_{a'}}$$

where

$$C_{a'} = qUC_u + (1 - q)\, U'\, C_u'$$

and q is derived from knowledge of C_d at DDI = 1, from the following three equations:

$$C_d = \left[q\right]\left[\frac{D_a}{C_a}(1 - U)\, C_u + (1 - \frac{D_a}{C_a})\ (1 - U')\, C_u'\right]$$

$$+ \left[1 - q\right]\left[(1 - U')\, C_u'\right]$$

$$(1 - U')\, C_u' = C_o$$

$$DDI = \frac{(1 - X)\, C_x}{C_d} = 1$$

By combining these equations:

$$(1 - X)\, C_x = q\left[\frac{D_a}{C_a}(1 - U)\, C_u - \frac{D_a}{C_a} C_o\right] + C_o$$

$$q = \frac{(1 - X)\, C_x - C_o}{\frac{D_a}{C_a}\left[(1 - U)\, C_u - C_o\right]} = \frac{C_o - (1 - X)\, C_x}{\frac{XC_x}{UC_u} \cdot \frac{D}{C_x}\left[C_o - (1 - U)\, C_u\right]}$$

Therefore, ADI is computed as follows:

$$ADI = \frac{XC_x}{C_a'} = \frac{XC_x}{qUC_u + (1 - q)\, U'C_u'}$$

(b) If $\frac{D_a}{C_a} > 1$, then C_d is computed by assuming an operating strategy with preemptive arrival priority (i.e., U percent arrivals) for p of the hour and at U´ percent arrivals for (1 - p) of the hour such that percent arrivals over the hour is set to X.

In this situation, values of DDI and ADI depend on the relative values of C_u, C_x, U, and X.

If $C_u \leq C_x$, there are no "excess" arrivals or departures; therefore, C_a and C_d are computed as follows:

$$C_a = XC_x$$

$$C_d = (1 - X)\ C_x$$

For the values of C_a and C_d computed above, both ADI and DDI = 1.

If $C_u > C_x$, and $U < X$, there are "excess" departures but no "excess" arrivals. Therefore, C_a and C_d are computed as follows:

$$C_a = XC_x$$

$$C_d = (1 - U)\ C_u$$

For the values of C_a and C_d computed above, ADI = 1, and DDI is computed as follows:

$$DDI = \frac{(1 - X)\ C_x}{(1 - U)\ C_u}$$

If $C_u > C_x$, and $U \geq X$, there may be "excess" arrivals.

Excess arrivals occur when $(1 - U)C_u = C_o$, and for this condition C_a and C_d are computed as follows:

$$C_a = UC_u$$

$$C_d = (1 - X)\ C_x$$

No excess arrivals occur when $(1 - U)\ C_u < C_o$, and for this condition C_a and C_d are computed as follows:

$$C_a = XC_x$$

$$C_d = (1 - X)\ C_x$$

For the values of C_a and C_d computed above, DDI = 1, and ADI is computed as follows:

$$ADI = \frac{XC_x}{C_a}$$

The above equations to compute ADI and DDI were used to produce the curves shown in Figures 2-70 through 2-102 of the Handbook. In some cases the curves were smoothed for ease of presentation.

Delay Production

Procedures to compute delays to aircraft on a daily and annual basis are described in the Handbook. Figure IV-2 shows the relationship between annual demand, annual service volume, and annual delay computed using these techniques.

The production of hourly delay information presented in Chapter 2 of the Handbook is described in the following paragraphs.

Demand Less than Capacity. Based on the demand profile factor analysis, it was apparent that a practical range of demand profile factors at the majority of U.S. airports is from some 25% to some 50%. Thus, for the delay model production runs, for demands less than capacity, three sets of schedules incorporating varying demand levels were developed:

- Schedule Set 1: Peaked schedules; demand profile factor of some 50%.
- Schedule Set 2: Moderately peaked schedules; demand profile factor of some 35%.
- Schedule Set 3: Uniform schedules; demand profile factor of some 25%.

Production runs were made using these sets of schedules and the results are shown on Table IV-15 and Figure IV-13. While the basic schedules have 25%, 35%, and 50% of the hour's traffic in a 15-minute period, adjustments to the schedules to obtain the range of D/C ratios required for plotting the future resulted in variations from these basic 15-minute percentages.

Table IV-15

AVERAGE AIRCRAFT DELAY IN AN HOUR

Case	Demand Profile Factor	Ratio of Hourly Demand to Hourly Capacity	Average Aircraft Delay (minutes)
1	35	0.38	0.3
2	33	0.57	0.5
3	30	0.75	0.8
4	27	0.85	1.2
5	26	0.94	1.9
6	35	0.38	0.4
7	37	0.57	0.6
8	35	0.75	1.3
9	36	0.85	2.5
10	36	0.94	4.5
11	47	0.36	0.4
12	52	0.55	1.8
13	51	0.74	3.5
14	50	0.83	5.0
15	51	0.92	6.9
16	52	0.98	9.1
17	43	0.84	3.6
18	43	0.76	2.6
19	48	0.76	3.5

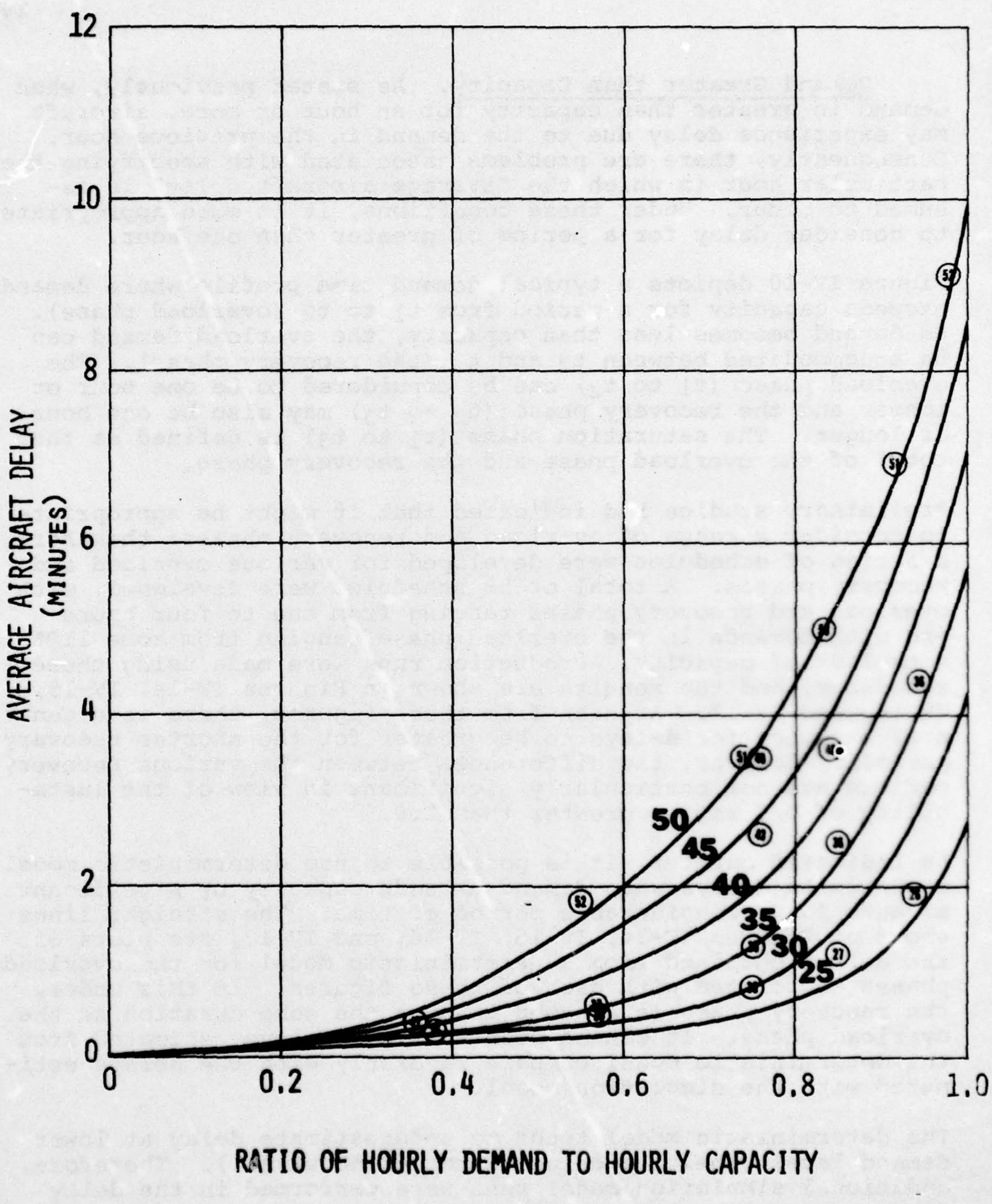


FIGURE IV-13. AVERAGE AIRCRAFT DELAY IN AN HOUR

Demand Greater than Capacity. As stated previously, when demand is greater than capacity for an hour or more, aircraft may experience delay due to the demand in the previous hour. Consequently, there are problems associated with specifying the particular hour in which the "average aircraft delay" is assumed to occur. Under these conditions, it is more appropriate to consider delay for a period of greater than one hour.

Figure IV-10 depicts a typical demand-time profile where demand exceeds capacity for a period from t_1 to t_2 (overload phase). As demand becomes less than capacity, the overload demand can be accommodated between t_2 and t_3 (the recovery phase). The overload phase (t_1 to t_2) can be considered to be one hour or longer and the recovery phase (t_2 to t_3) may also be one hour or longer. The saturation phase (t_1 to t_3) is defined as the total of the overload phase and the recovery phase.

Preliminary studies had indicated that it might be appropriate to consider a range of overload and recovery phases; therefore, a series of schedules were developed for various overload and recovery phases. A total of 58 schedules were developed, with overload and recovery phases ranging from one to four hours and with demands in the overload phase ranging from some 110% to some 140% of capacity. Production runs were made using these schedules, and the results are shown in Figures IV-14, IV-15, IV-16, and IV-17. As seen from these figures, there is a general tendency for delays to be greater for the shorter recovery periods. However, the differences between the various recovery periods are not particularly significant in view of the instability of D/C ratios greater than 1.0.

As indicated earlier, it is possible to use deterministic models to estimate delays when demand exceeds capacity by significant amounts for a considerable period of time. The straight lines shown on Figures IV-14, IV-15, IV-16, and IV-17, are plots of the delays obtained from a deterministic model for the overload phases associated with each of these figures. In this model, the recovery phase is assumed to have the same duration as the overload phase. It can be seen that the delays estimated from the deterministic model compare favorably with the delays estimated with the simulation model.

The deterministic model tends to underestimate delay at lower demand levels (below a delay factor of about 1.1). Therefore, additional simulation model runs were performed in the delay factor range from 1.0 to 1.1 to assist in developing the curves shown in Figure IV-18.

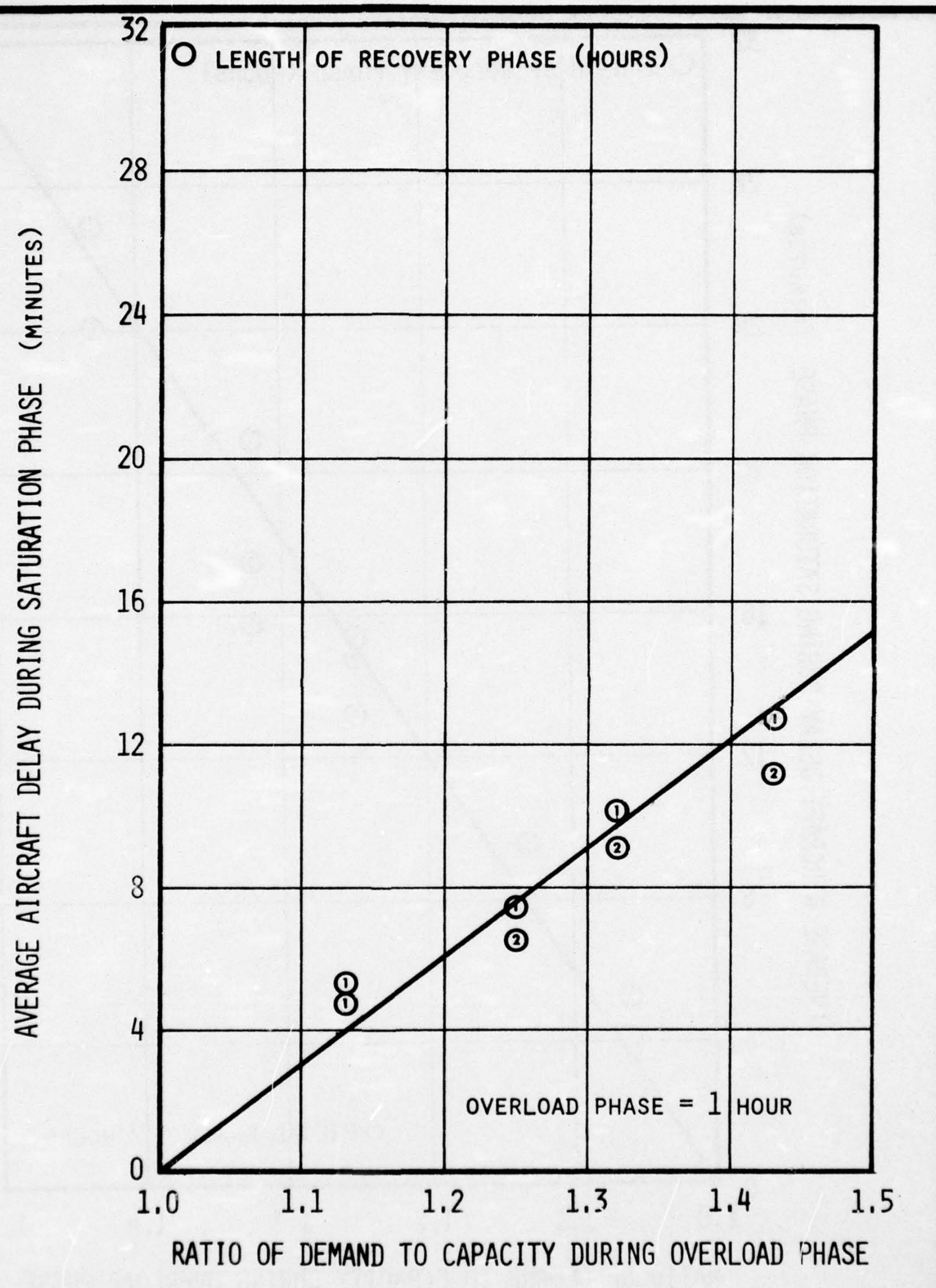


FIGURE IV-14. AVERAGE AIRCRAFT DELAYS WHEN OVERLOAD PHASE IS 1 HOUR

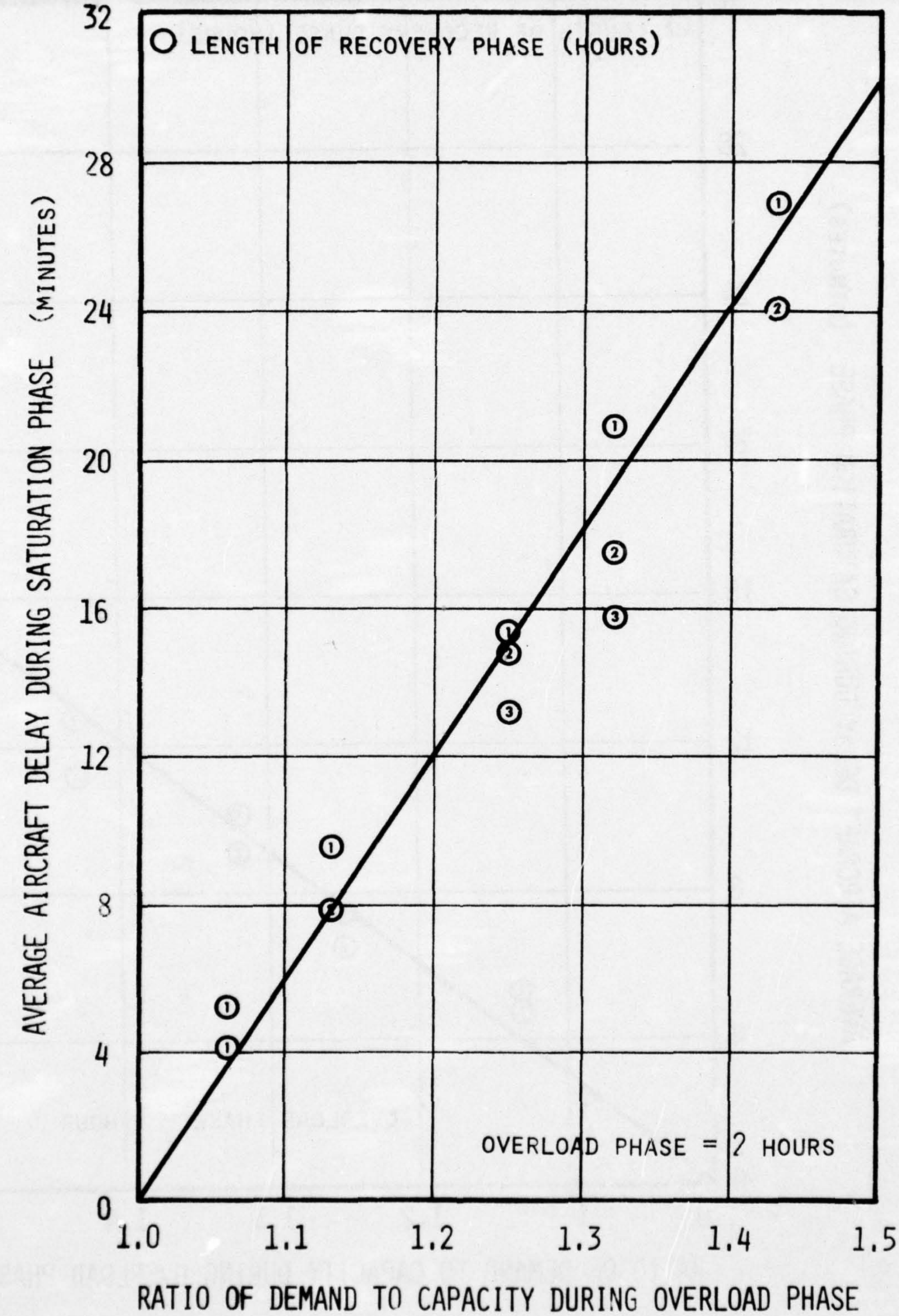


FIGURE IV-15. AVERAGE AIRCRAFT DELAYS WHEN OVERLOAD PHASE IS 2 HOURS

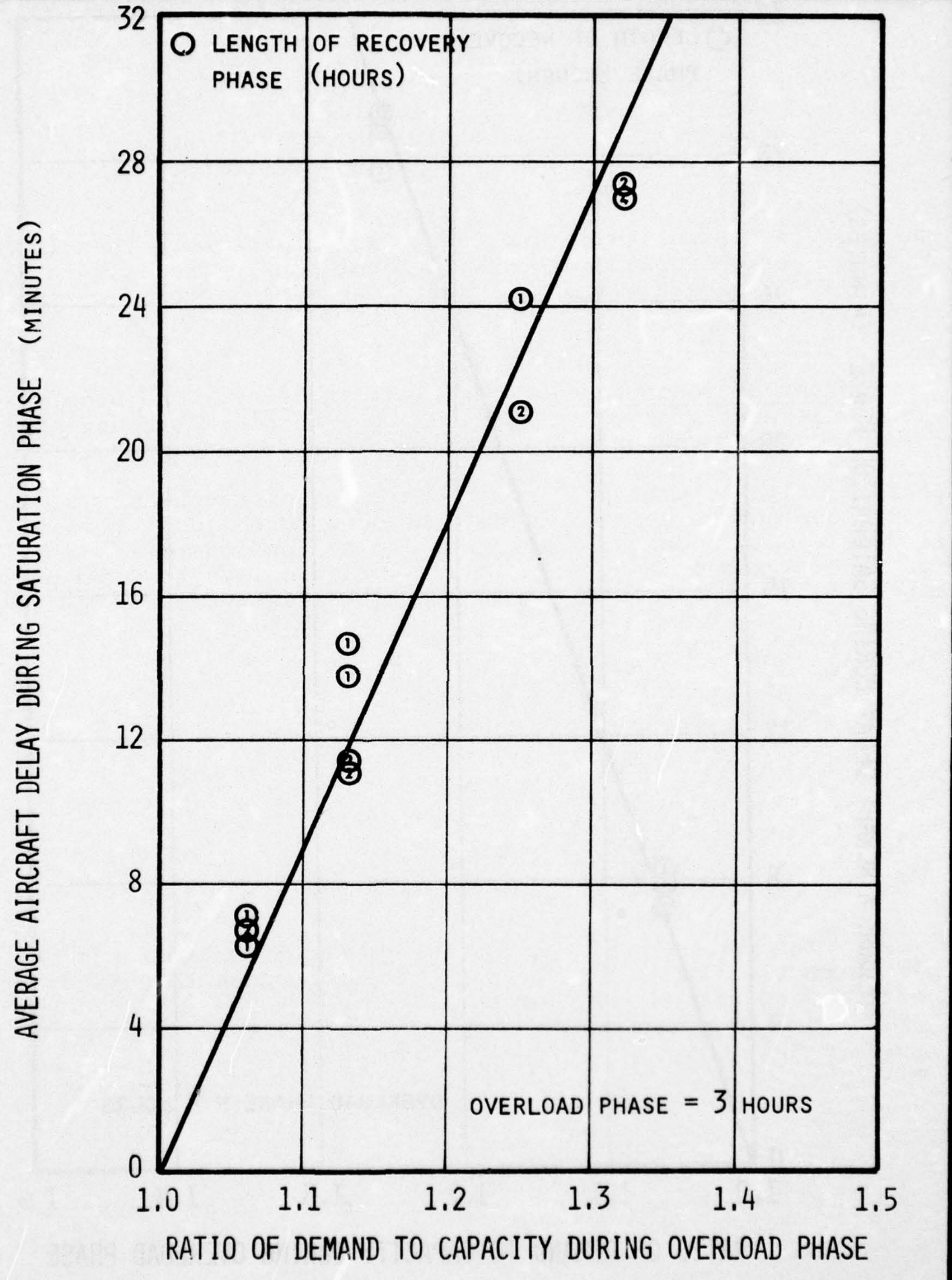


FIGURE IV-16. AVERAGE AIRCRAFT DELAYS WHEN OVERLOAD PHASE IS 3 HOURS

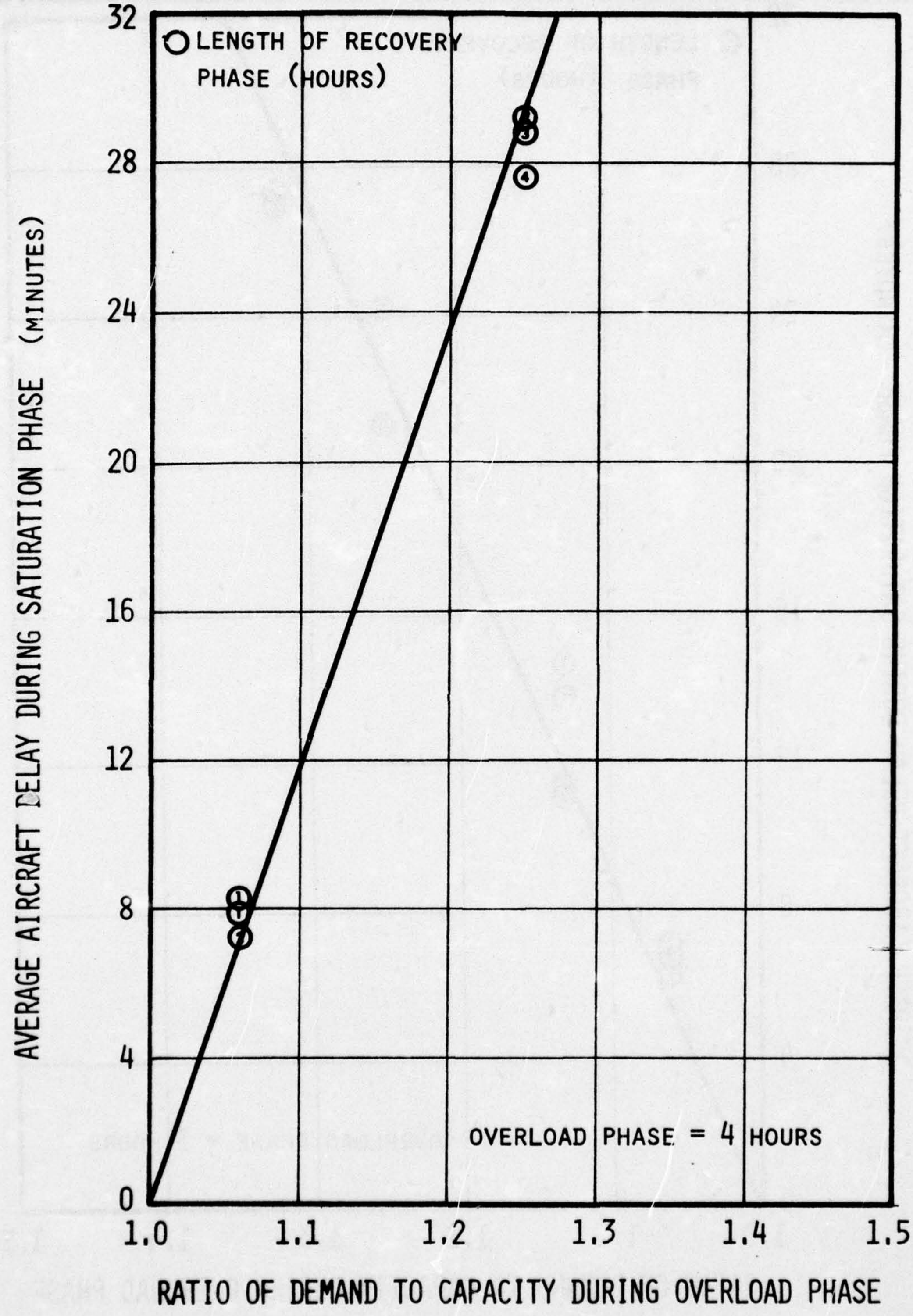


FIGURE IV-17. AVERAGE AIRCRAFT DELAYS WHEN OVERLOAD PHASE IS 4 HOURS

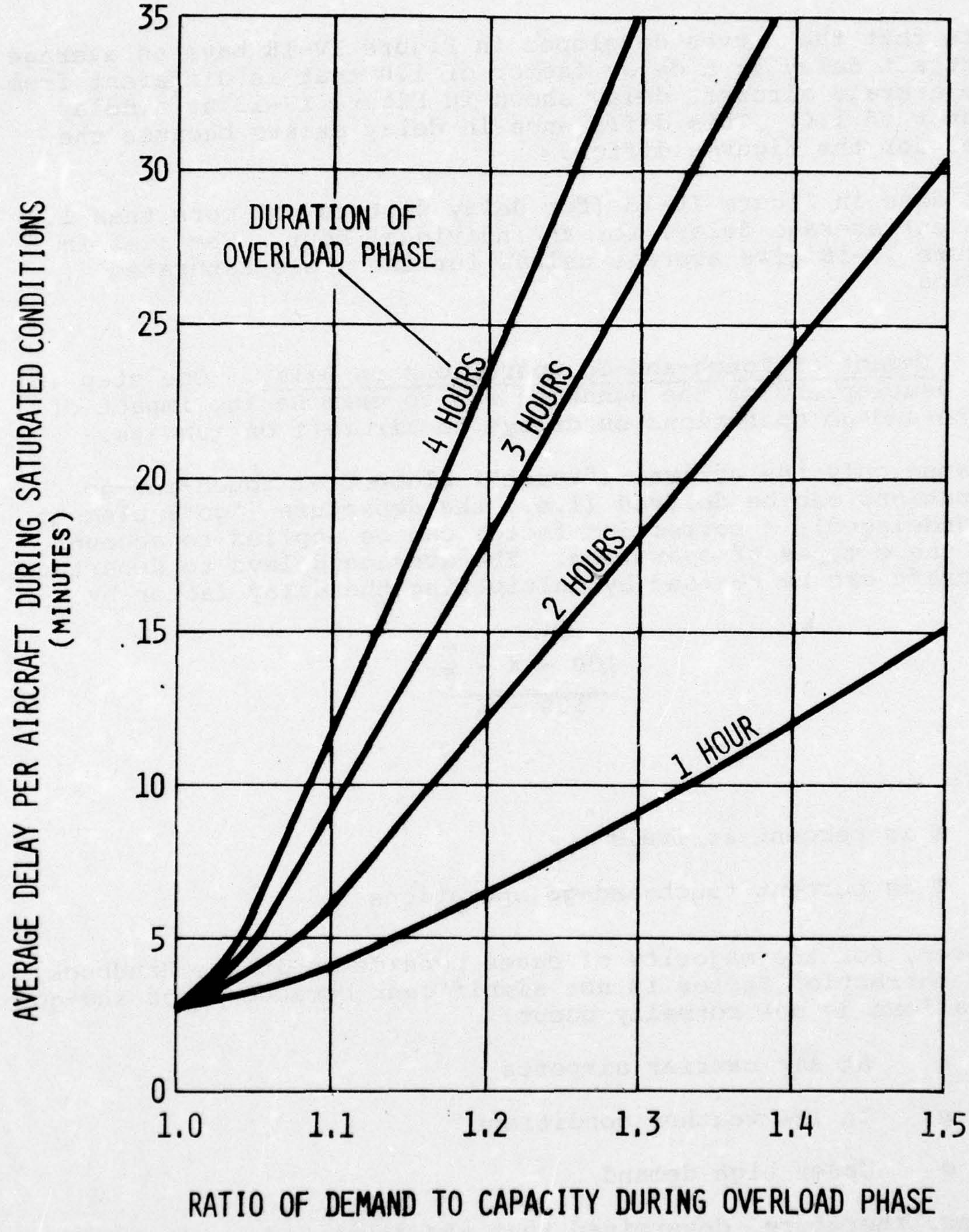


FIGURE IV-18. AVERAGE AIRCRAFT DELAY DURING SATURATED CONDITIONS

Note that the curves developed in Figure IV-18 have an average aircraft delay at a delay factor of 1.0 that is different from the average aircraft delay shown in Figure IV-13 at a delay factor of 1.0. This difference in delay exists because the axes for the figures differ.

The axes in Figure IV-13 (for delay factors not more than 1.0) present average delays for an individual hour. The axes in Figure IV-18 give average delays for the whole saturated period.

Impact of Touch-and-Go Operations on Delay. One step in the development of the Handbook was to examine the impact of touch-and-go operations on delays to aircraft on runways.

Because only the arrival ("touch") element of touch-and-go operations can be delayed (i.e., the departure ["go"] element is undelayed), a correction factor can be applied to account for these types of operation. The average delays to departure aircraft can be revised by multiplying the delay factor by

$$\frac{100 - X - \frac{T}{2}}{100 - X}$$

where

X is percent arrivals

T is percent touch-and-go operations

However, for the majority of cases considered in the Handbook, this correction factor is not significant because touch-and-go operations do not normally occur:

- At air carrier airports
- In IFR weather conditions
- Under high demand

It was, therefore, determined that the touch-and-go correction factor for delays described above should not be presented in the Handbook.

Model Inputs. The production runs for both demands less than and greater than capacity were made using the schedules described in the previous sections on a single runway configuration. Each run consisted of operating the model using ten random number seeds and averaging the results. Aircraft operational data used in the delay model production runs were the same as those data used in the capacity model production runs (where applicable).

LIST OF NUMBERED REFERENCES

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